CHAPTER 3

NAVAL SECURITY GROUP ELECTRONIC SYSTEMS

As mentioned in the previous chapter, this text will not repeat basic electronic theory. It is therefore essential that the technician review the following subjects in *Basic Electronics*, NAVEDTRA 10087: Fundamentals of Communications Theory, Transmission Lines, Wave Propagation, and Antennas.

As a CTM 3 or 2, you will develop skills required for the operation, maintenance, and repair of complex electronic systems, related electro-mechanical devices, and a wide variety of equipments utilized as components of radio communication systems. You will also learn the accounting and administrative functions necessary to perform your duties as a maintenance technician.

The CTM's duties are primarily systems oriented. A communications system must be understood to include all the subsystems necessary to transmit data from the originator's source equipment to the user's end product device in whatever form required. Any radio communications system may be broken down into separate subsystems which encompass the various types of equipment required to perform the functions of the subsystem.

A Communications System consists of: (1) the receiver RF Distribution Subsystem which includes the transmission media, the antenna, the RF transmission line(s), and RF distribution; (2) the Receive Subsystem which consists of the radio receivers; (3) the Record/Reproduce Subsystem which include a number of different types of long and short term storage and recovery devices; (4) the Communication Subsystem wherein the signal is

converted to a usable form; (5) and the Data Processing Subsystem which includes various types of modern computerized equipment. On the transmit side, the Transmit Subsystem includes the signal processing equipment wherein information, either electrical or mechanical, is converted into a properly coded signal and sent to the Transmit Subsystem where the signal is converted to RF energy; and the transmit Radio Frequency (RF) Distribution Subsystem in which the transmitter's RF output is carried via the transmission line(s) and coupling devices to an antenna where it is radiated into the ionosphere.

Within the Communications System there are many types of equipments utilized to fulfill the mission of the station. There are signal converter devices which process and ultimately convert the output of a receiver or landline into usable data or prepare data for transmission; teletypewriter devices which convert electrical signals to or from mechanical operations; data processing equipments which perform calculations, compile information, and provide updated and accurate control information; radio direction finder equipments which display receiver video signals; and magnetic recorders which provide a means of storage or buffering and recovery of desired data.

Other subsystems are also discussed in this rate training manual (RTM) which are not included in any of the broad areas previously covered, but are subsystems which are directly related and are complimentary to the various electronic subsystems as shown in figure 3-1. These are the Time Frequency, Power Source, Environmental, and Facilities subsystems.

Any equipment that you will be tasked to maintain can be considered a component of one
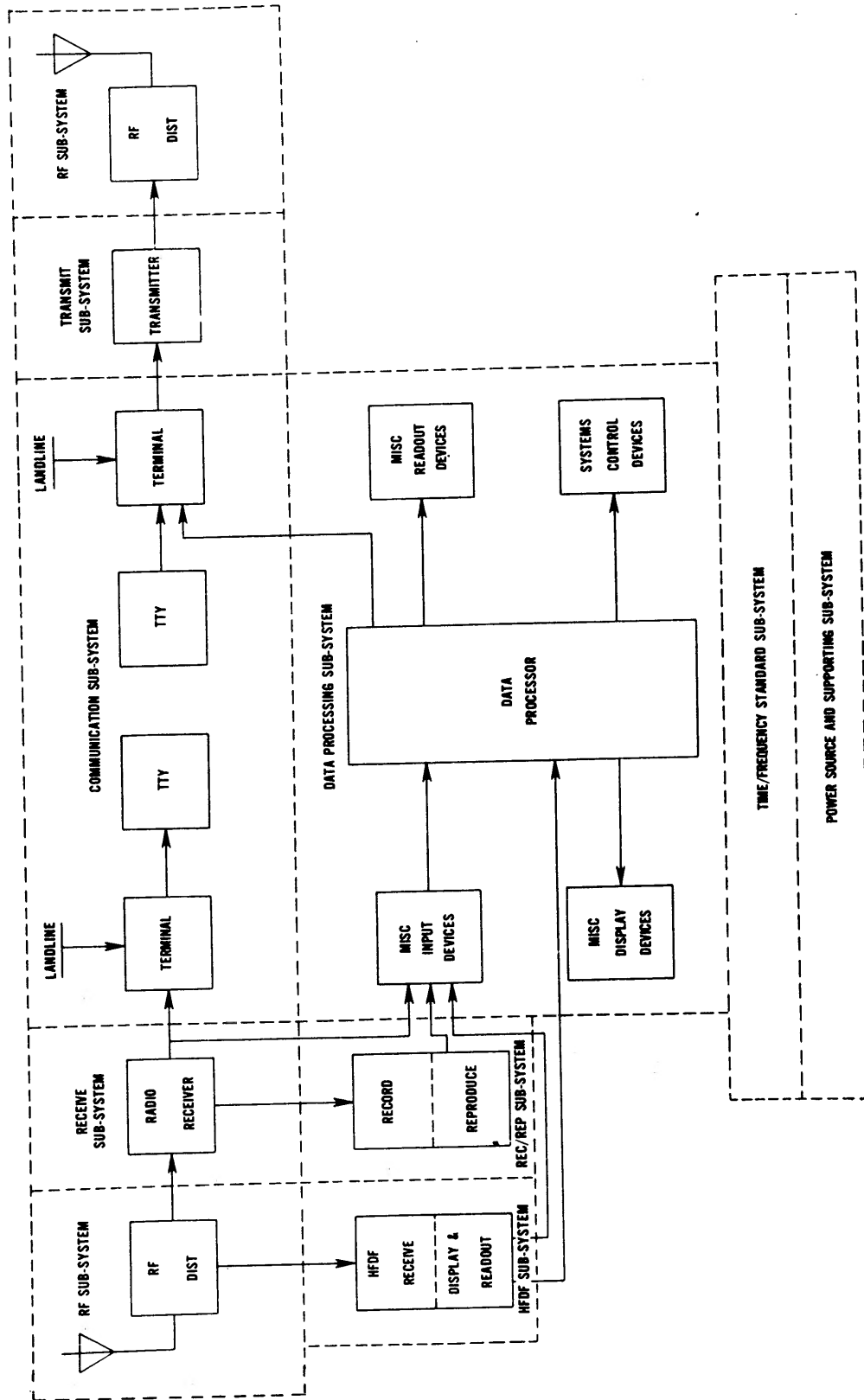
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Figure 3-1.—Typical Electronic System of a NAVSECGRU Activity.

of the subsystems discussed above and will be a component of a whole system. You should consider each individual equipment as a system component, learn the relationship of this equipment to the other system components, and use this knowledge in the performance of your respective maintenance duties.

THE MASTER CLOCK SUBSYSTEM

TIME/FREQUENCY STANDARDS

Transmitters and receivers operating in a single-sideband mode and using narrow-shift Frequency-Division Multiplex (FDM) require close frequency tolerances to pass several channels of data. These tolerances become more stringent as the frequency shift decreases and the complexity of the communications operation increases, as is the case when various geographically separated stations transmit individual narrow-shift data channels utilizing a common transmitter frequency for reception by a single control station. In a case such as this, to keep other stations from interfering with each other's data, total frequency variations in the entire system might be required to be less than ten hertz. There are various equipments which require the input of exact time for computation purposes, for recording the occurrence of events, and for synchronous operation of physically separated systems. In each of the above cases, the proper operation of the equipment is dependent upon extremely accurate time or frequency sources.

Types of Frequency Standards

At the present time, three types of frequency standards are in common use. These are the cesium atomic beam controlled oscillator, the rubidium gas cell controlled oscillator (which will not be discussed here), and the quartz crystal oscillator. The first type is a primary frequency standard and the last two are secondary frequency standards. The distinction between a primary standard and a secondary standard is that the primary standard does not require any other reference for calibration; whereas the secondary standard requires calibrations both during manufacturing and at intervals during use, depending on the accuracy desired.

Quartz oscillators are used in virtually every frequency control application including atomic standards. For less demanding applications where some long-term drift can be tolerated, quartz oscillators are used as independent frequency sources.

The first type of frequency standard to be discussed in this chapter will be the AN/GSQ-53 Time Signal Set which uses an internal quartz crystal oscillator as a reference.
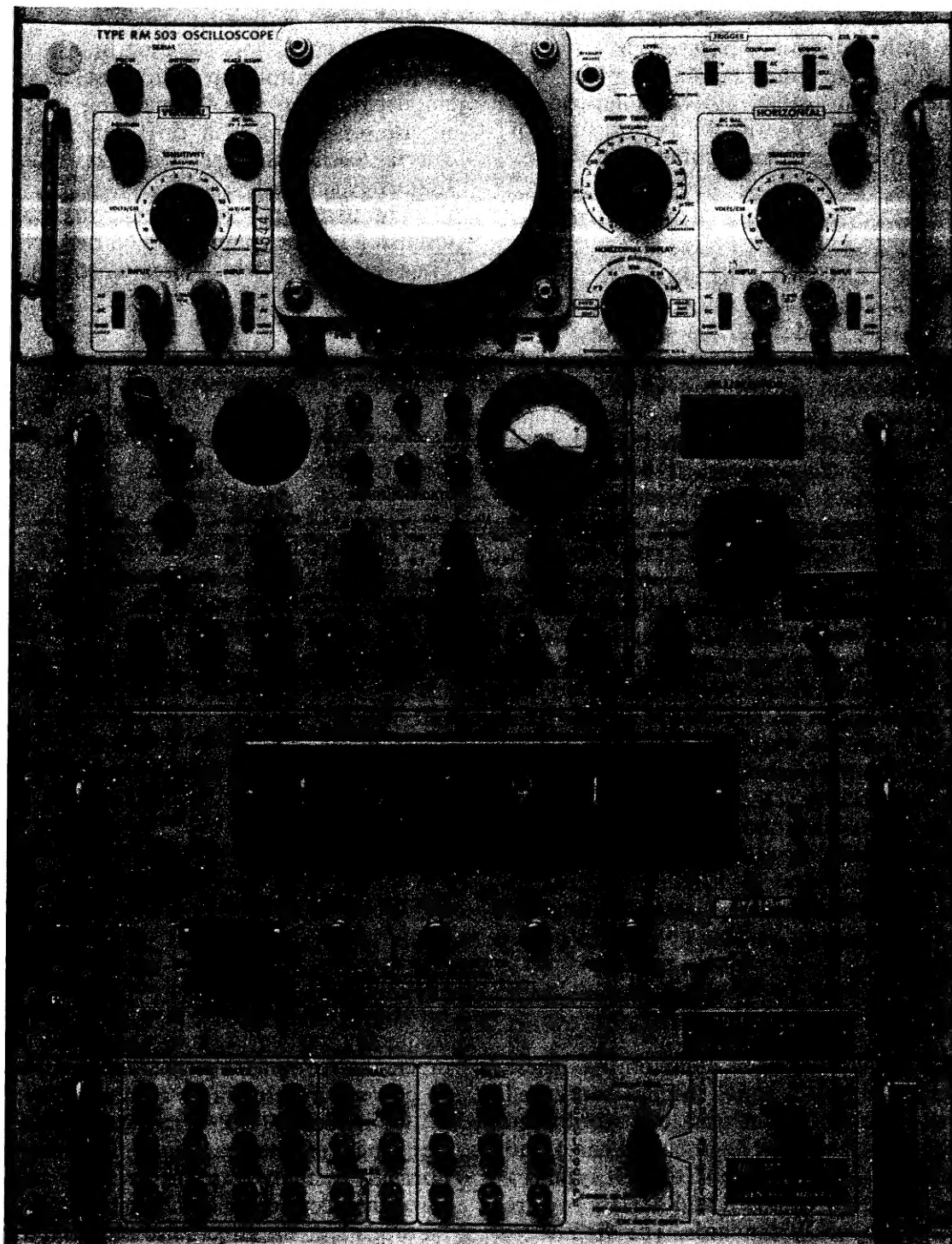
Time Signal Set AN/GSQ-53

The AN/GSQ-53 Time Signal Set is one example of the type of equipment used in a Master Clock Subsystem.

The AN/GSQ-53 (figure 3-2) is designed to provide stable frequencies and real-time information for signal analysis and data automation equipment. This equipment has a timing network synchronization capability of significantly less than 100 microseconds.

The AN/GSQ-53 equipment (figure 3-3) consists of the following major assemblies: VLF phase-comparison equipment, time-generating equipment, control-indicator group, and an auxiliary equipment group. The auxiliary equipment includes: digital display indicators, program clock, program clock control, electronic marker generator and battery box.

VLF PHASE-COMPARISON EQUIPMENT.—Frequency is dependent upon time, and conversely, generators of constant frequency can be used to drive time integrator or clocks for long time measurements. In order to prevent an intolerable accumulation of error, it is necessary to periodically correct the frequency of the standards. Two methods are normally employed to make these corrections through reception of radio transmissions. These methods are: the time-pulse method, which will not be discussed here, and by direct comparison of the transmitted carrier frequency with the "local standard" method. The direct-comparison method is the method used to monitor the standards in the AN/GSQ-53 system. Above

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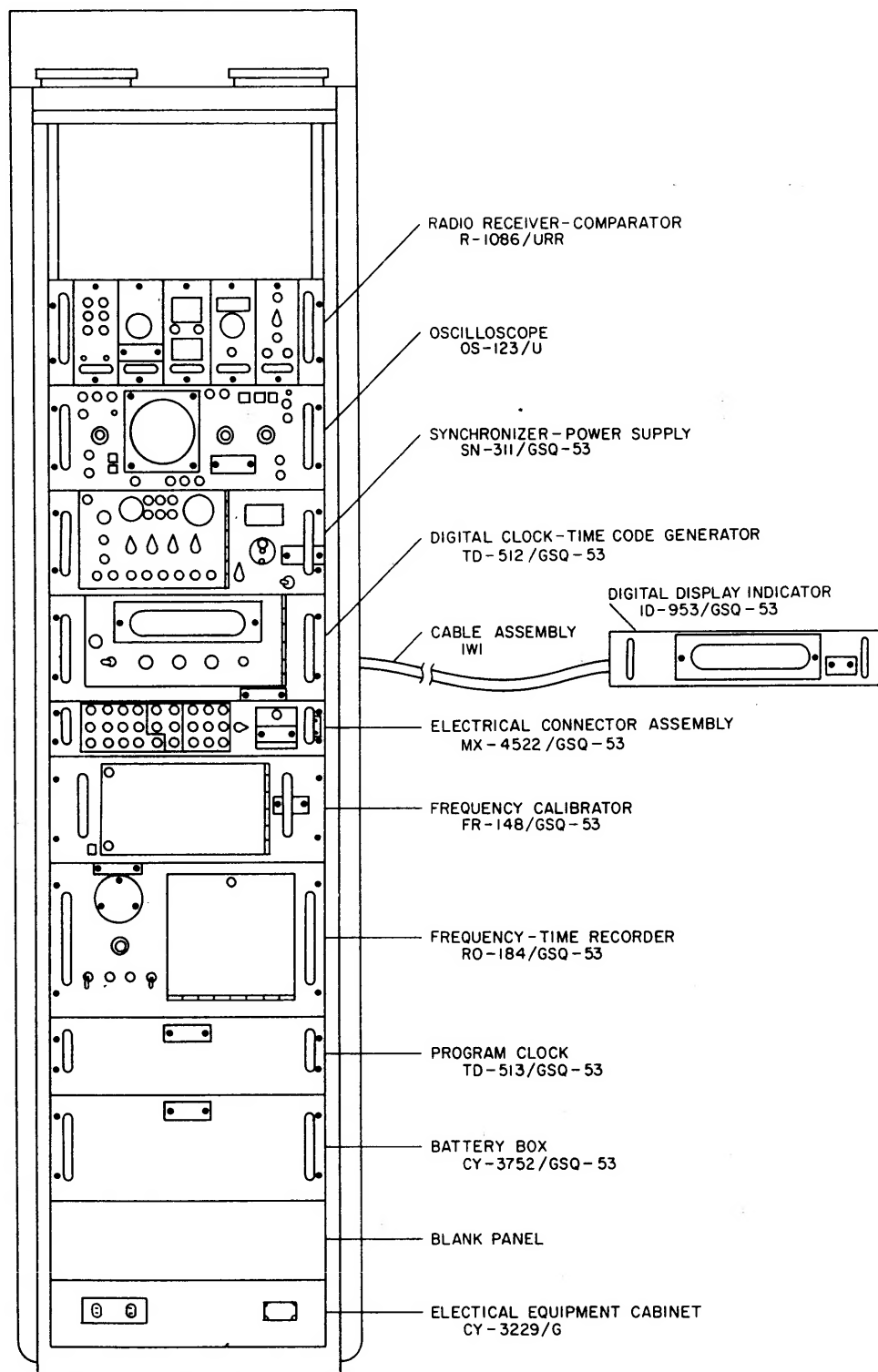Figure 3-2.—Time Signal Set, AN/GSQ-53 Front View.

RADIO RECEIVER–COMPARATOR
R–1086/URR

OSCILLOSCOPE
OS–123/U

SYNCHRONIZER–POWER SUPPLY
SN–311/GSQ–53

DIGITAL CLOCK–TIME CODE GENERATOR
TD–512/GSQ–53

DIGITAL DISPLAY INDICATOR
ID–953/GSQ–53

CABLE ASSEMBLY
1W1

ELECTRICAL CONNECTOR ASSEMBLY
MX–4522/GSQ–53

FREQUENCY CALIBRATOR
FR–148/GSQ–53

FREQUENCY–TIME RECORDER
RO–184/GSQ–53

PROGRAM CLOCK
TD–513/GSQ–53

BATTERY BOX
CY–3752/GSQ–53

BLANK PANEL

ELECTICAL EQUIPMENT CABINET
CY–3229/G

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Figure 3-3.—Time Signal Set, AN/GSQ-53 Line Drawing.

100 kHz, the accuracy of comparison is limited by Doppler shifts caused by ionospheric variations. In general, one part in 10^7 or 10^8 is the most accurate that can be expected. However, in the VLF range (12 to 30 kHz), the reflecting layers in the ionosphere are relatively constant most of the day, permitting comparison to a few parts in 10^{10} by observing the phase relation between the transmitted carrier and the "local standard".

Radio Receiver-Comparator (R-1086/URR).—An R-1086/URR VLF tracking receiver is used for reception of VLF in the 12 to 30 kHz band. Its primary function is to measure the relative phase between the transmitted VLF frequency and a locally generated frequency, functioning even if the received signal is below the noise level. The equipment consists basically of four fixed-tuned receiver channels, a synthesizer for producing local references, a phase detector, a servo system and a continuously variable phase shifter, a means for continuously recording relative phase, and an audio output for monitoring the VLF signal. The PHASE SERVO module output drives the Frequency-Time (chart) Recorder, which provides a direct reading of time loss or gain over a given time interval. One microsecond of time lost or gained as indicated by the chart recorder, means the phase of the local one MHz signal has retarded or advanced one hertz with respect to the VLF carrier.

Frequency - Time Recorder (RO-184/GSQ-53).—The frequency-time recorder contains a galvanometer movement pen recorder driven by the recorder output of the Tracking Receiver. Full scale deflection indicates 100 microseconds of time lost or gained. The chart record data is used to make two corrections: (1) Frequency drift is determined from the slope of this record and used to correct the Frequency Calibrator. (2) Time lost or gained is read directly and the clock is advanced or retarded by the proper amount to compensate for the oscillator frequency deviation.

TIME CODE GENERATING EQUIPMENT.—Generation of time codes is accomplished by the Digital Clock-Time Code Generator. The output from the Frequency Calibrator drives the phase shifter circuitry in the Synchronizer. The output of the phase shifter is used on the Digital Clock-Time Code Generator input signal.

Synchronizer-Power Supply (SN-311/GSQ-53).—The Synchronizer Power Supply Unit provides four functions of the AN/GSQ-53 set: (1) The Synchronizer contains the digital delay circuitry which compensates for radio signal propagation delay. This delay is adjustable in 0.1 millisecond steps from zero to 99.9 milliseconds. (2) A phase shift circuit is included to allow the operator to advance or retard the Digital Clock-Time Code Generator. (3) The alarm circuitry monitors the major signals and voltages of the AN/GSQ-53 and provides a visual and audible alarm in the event of failure in any of the monitored circuits.(4) The power supply provides -12 VDC, -6 VDC, +12 VDC, +180 VDC and high voltage output (360-400 VDC).

Digital Clock-Time Code Generator(TD-512/GSQ-53).—The Digital Clock-Time Code Generator contains digital dividers, binary-coded decimal counters, and Nixie indicators to provide a visual indication of time. The 10 kHz input is divided by the frequency dividers to obtain 10 pps clock-drive pulses. The decimal counters provide a binary-coded decimal output representing time to 0.1 second resolution. The binary-coded decimal-time code is converted to a decimal readout by a diode decoder and is displayed by the Nixie indicators. The parallel BCD code is also converted to both analog and digital serial time code. These outputs are available from the Digital Time-Code Generator at the Electrical Connector Assembly.

Frequency Calibrator (FR-148/GSQ-53). The Frequency Calibrator generates stable output frequencies of five MHz, one MHz, 100 kHz, one kHz, 100 and 60 hertz. The output waveform is sinusoidal. The unit uses a five MHz quartz crystal oscillator circuit and is mounted in a double proportional oven. A stabilized feedback amplifier is used with an AVC system to maintain the crystal power at a low constant value necessary for frequency stability.

Electrical Connector Assembly (MX-4 5 2 2/GSQ-5 3).—The Electrical Connector Assembly provides front and rear panel access to the output frequencies and time codes of the AN/GSQ-53. When the Electronic Marker Generator is a part of this system, it is located in the Electrical Connector Assembly.

Oscilloscope (OS-123/U).—The Oscilloscope is a low frequency, high sensitivity, laboratory-type instrument, providing accurate time and amplitude measurements in the range from d.c. to 450 kHz. The Oscilloscope is used to obtain coincidence between the delayed one-pps clock output from the Synchronizer and the received radio time pulse.

AUXILIARY EQUIPMENT.—Additional equipment may be used to increase the capabilities of the AN/GSQ-53 system. These items are described in the following paragraphs.

Digital Display Indicator (I D-9 5 3/G S Q-5 3).—The Digital Display Indicator provides visual time indications at any desired location in the facility. Nixie indicators are connected in parallel with the Digital Clock-Time Code Generator indicators to provide the same time indication at a remote location.

Program Clock (TD-5 1 3/GSQ-53).—The Program Clock provides the voice time announcement of the time of day. Pre-recorded spoken digits, zero through nine, are stored on a magnetic drum and the digits to be announced are selected by the output of the Digital Clock-Time Code Generator. Two types of outputs are provided: continuous time announcement and time-on-demand announcement.

A continuous time announcement of five words every ten seconds, with exact time indicated by a tone burst before the announcement.

A time-on-demand announcement is supplied when a request for time is made from a remote location. A time demand can be made and answered every five seconds. Each remote location will require a Control, Program Clock unit to activate the time-on-demand function.

Electronic Marker Generator (0-1 0 4 7 / G S Q-5 3).—The Electronic Marker Generator provides ruler time markers synchronized with real time. COARSE and FINE RULER signal formats provided as outputs are shown in figure 3-4.

The COARSE RULER is generated by doubling the amplitude of a one-kHz tone. As shown in figure 3-4A it provides one minute intervals indicated by three bursts of a one kHz tone of 1/10th of 2 second duration, and spaced 1/10th of a second apart. Ten-second intervals are indicated by two bursts of one kHz tone of 1/10th of a second duration , and spaced 1/10th of a second apart. One second intervals are indicated by a burst of one kHz tone of 1/10th of a second duration.

The FINE RULER (figure 3-4B) provides time signals by doubling the amplitude of a basic five kHz tone. One-second intervals are indicated by five groups, each of five cycles high amplitude separated by five cycles of low amplitude. 0.1 second intervals are indicated by three groups, each five cycles high amplitude separated by five cycles of low amplitude. 0.01 second intervals are indicated by a single group of five cycles of low amplitude. 0.001 second intervals are indicated by a single cycle of high amplitude. 0.0001 second intervals are indicated by the cross over points of the basic five kHz tone.

Battery Box (CY-3752/GSQ-53).—The Battery Box supplies standby power for the Frequency Calibrator, Synchronizer-Power Supply, and Digital Clock-Time Code Generator. The equipment automatically switches to the Battery Box in case of AC line failure.

AN/GSQ-53 SIGNAL FLOW.—Signal flow within the Time Signal Set AN/GSQ-53 is shown in figure 3-5. The two major groups of equipment are the VLF equipments which consists of the Receiver - Comparator and a Frequency-Time Recorder, and the Time Generating Equipment which consists of the Synchronizer-Power Supply, Digital Clock-Time Code Generator, Frequency Calibrator, Electrical Connector Assembly, and Oscilloscope. The input signal used by the AN/GSQ-53 are the outputs of the
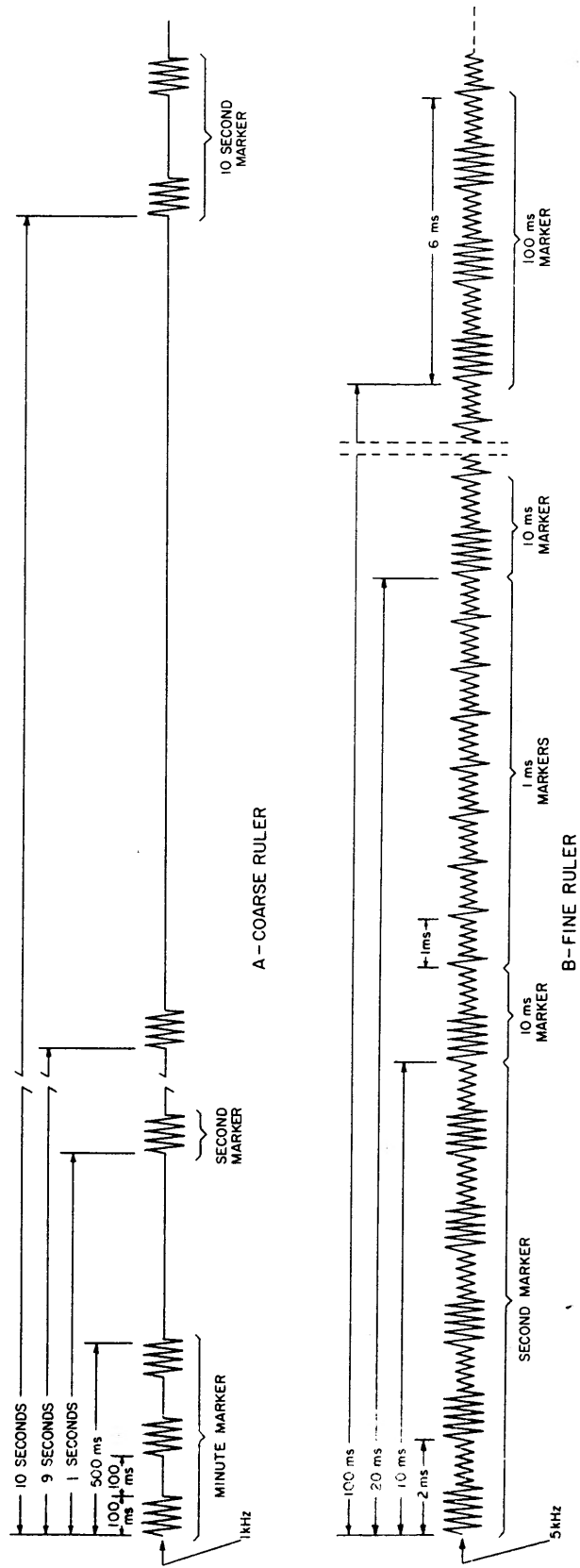
Figure 3-4.—Coarse and Fine Ruler Pulse Train Structures.

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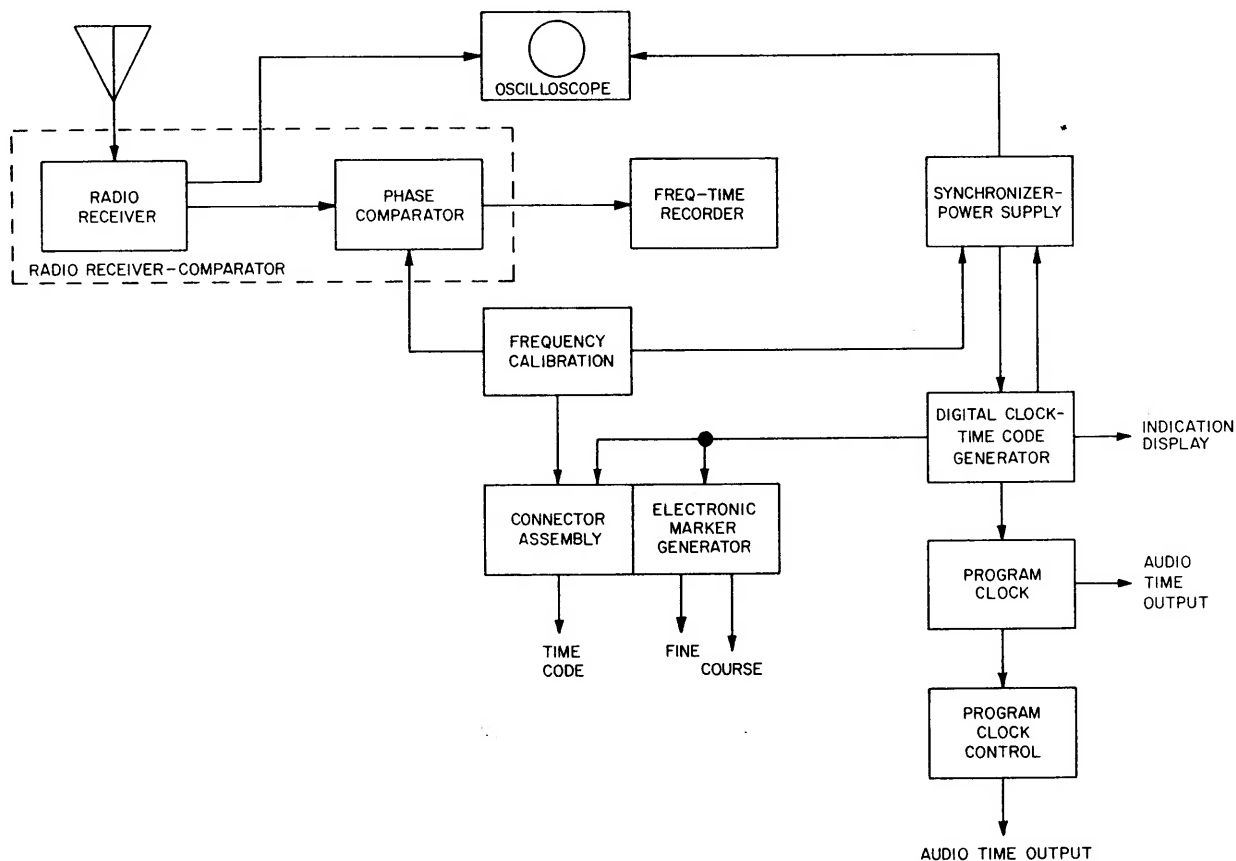
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Figure 3-5.—Time Signal Set AN/GSQ-53, Block Diagram.

Receiver-Comparator which are used for phase comparison and HF time transmissions synchronization.

VLF Equipment.—The VLF signal is received by the Receiver-Comparator. The comparator measures the phase difference between the received signal and the Frequency Calibrator output. The phase difference between the two signals is recorded as cumulative time error by the Frequency-Time Recorder. The "on line" oscillator correction is determined from the chart data. The clock is also advanced or retarded by the amount of time gained or lost.

Time Generating Equipment.—The Frequency Calibrator outputs are applied to the

Synchronizer-Power Supply, Electrical Connector Assembly, and to the Comparator. The Electrical Connector Assembly outputs are for external use.

Atomic Frequency Standards

Starting with the initial usage of Atomic Frequency Standards as the reference standard in national laboratories, the applications of atomic standards have expanded to include use in such operational systems as navigational transmitter and receiver systems, satellite tracking and guidance stations, geophysical survey positioning systems and communications systems.

CESIUM BEAM FREQUENCY STANDARD CAQI-5061A.—The Cesium Beam Frequency Standard CAQI-5061A (figure 3-6) is an atomic frequency standard which is used at some Naval Security Group stations as the primary frequency standard. The accuracy of the CAQI-5061A is ±5 parts in 10^{12} with negligible long-term drift and no need for calibration. The absolute accuracy, intrinsic reproducibility and absence of any perceptible long-term drift or aging are important advantages of the CAQI-5061A.

CAQI-5061A Signal Flow.—Signal flow within the CESIUM BEAM FREQUENCY STANDARD CAQI- 5061A is shown in figure 3-7. The output of the 5MHz Crystal Oscillator Assembly A10 is phase modulated by a 137 Hz signal from the Phase Detector Assembly A8. The modulation index is kept small to keep modulation distortion low. The modulated 5 MHz signal is multiplied by 18 in the Multiplier Assembly A3, and then by 102 in the Harmonic Generator Assembly A4. The output from the Synthesizer Assembly A1 is also derived from the 5 MHz quartz oscillator, and is mixed with the multiplied signal in the Harmonic Generator Assembly A4. The results of the multiplying and mixing is a frequency very close to the Cesium 133 transition frequency. This finalized microwave field is applied to the cesium beam tube.

Since the 5 MHz quartz oscillator frequency was phase modulated by 137 Hz in Multiplier Assembly A3, the finalized microwave field contains this modulation. When the
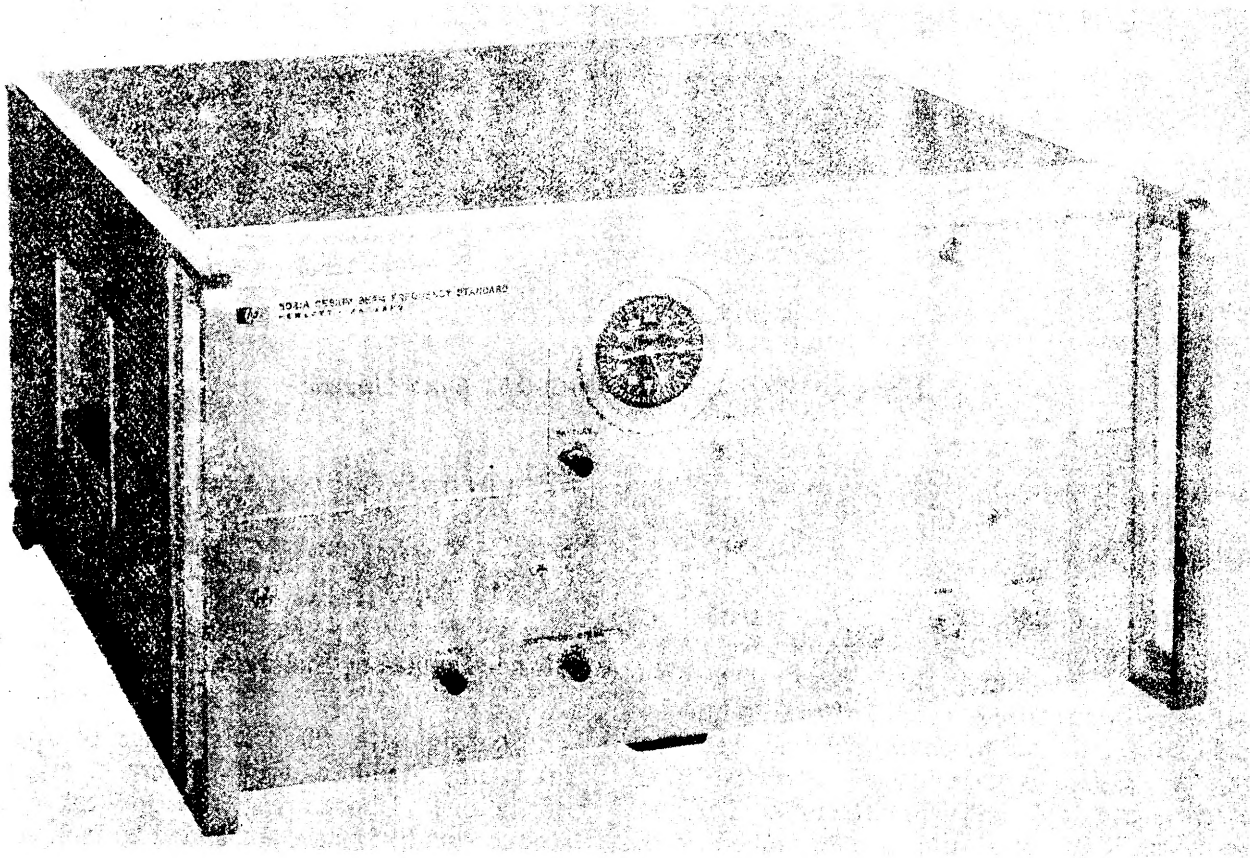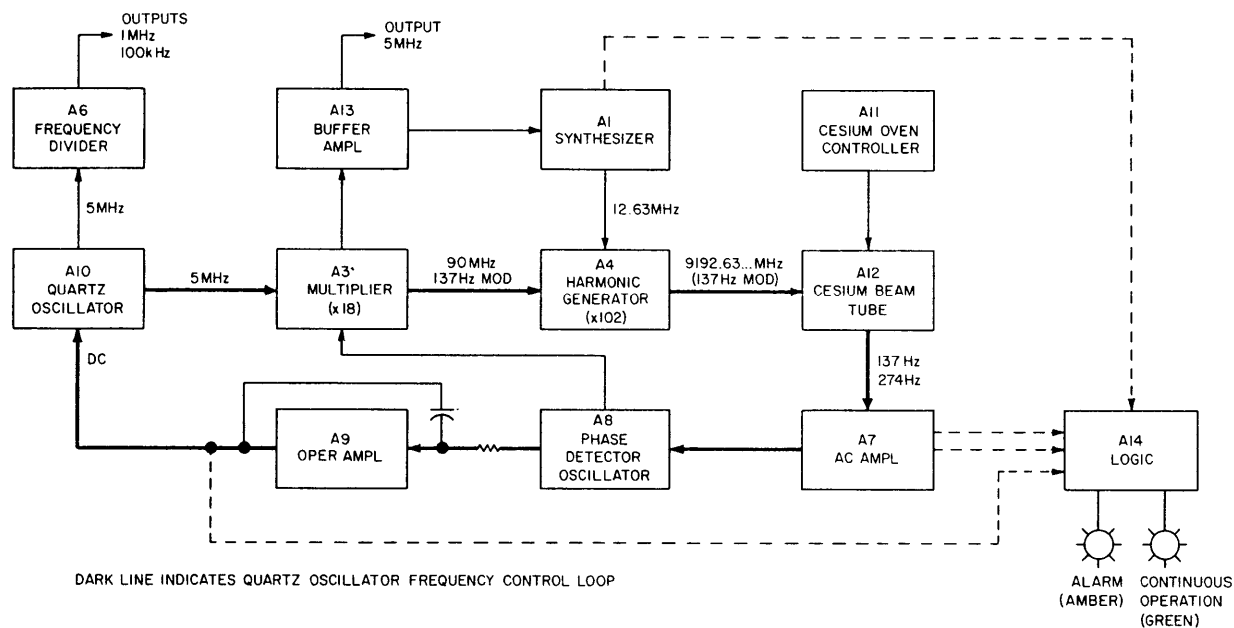

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Figure 3-6.—Cesium Beam Frequency Standard CAQI-5061A.

DARK LINE INDICATES QUARTZ OSCILLATOR FREQUENCY CONTROL LOOP

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Figure 3-7.—Basic Block Diagram of Cesium Beam Frequency Standard CAQI-5061A.

phase-modulated microwave field is precisely at the peak of cesium resonance, the cesium beam tube output is the second harmonic (274 Hz) of the modulation frequency. When off of the peak, the output is the fundamental frequency (137 Hz). These two frequencies are separated in the AC Amplifier Assembly A7. The 137 Hz signal is sent to the Phase Detector Assembly A8 and the Logic Assembly A14. The 274 Hz signal is also sent to the Logic Assembly A14.

The output from the Phase Detector Assembly A8 is a d.c. voltage proportional to the difference in the frequency between the cesium resonance and the applied microwave field. The d.c. signal is supplied to the Operational Amplifier and Integrator A9.

The output of the Operational Amplifier A9 is a voltage which electrically tunes the 5 MHz quartz oscillator to eliminate any frequency difference between the cesium beam tube resonance and the microwave field.

The Buffer Amplifier Assembly A13 isolates the 5 MHz quartz oscillator signal from external loading effects and provides 5 MHz signals to front and rear panel output jacks.

The Frequency Divider Assembly A6 divides the 5 MHz signal to 1 MHz and 100 kHz signals and provides these signals to front and rear panel output jacks. This assembly also supplies 1 MHz to the Digital Divider Assembly A5.

The Logic Assembly A14 receives signals from assemblies A1, A7, A8, and A9 to control front panel CONTINUOUS OPERATION and ALARM lights.

The Cesium Oven Controller A11 provides power to the cesium beam oven and Operational Amplifier Assembly A9.

THE RADIO FREQUENCY (RF) SUBSYSTEM

RADIO WAVES

Radio waves are a form of electromagnetic radiation similar to light and heat waves. They differ from other radiations only in the manner in which they are generated and detected, and in their frequency range which is from approximately 3 kHz to 300 GHz. The radio frequency spectrum is divided into various bands

of frequencies as shown in figure 3-8. Radio waves travel at the same velocity as light waves, which in free space have a speed of approximately 186,000 miles-per-second or 300,000,000 meters-per-second. The wavelength of a radio signal expressed in meters is the distance that the wave travels in one cycle at a given frequency. Radio wave propagation, polarization, reflection, diffraction, and type are dealt with in their entirety in *Basic Electronics*, NAVEDTRA 10087, and therefore will not be repeated here.

SATELLITE COMMUNICATIONS

Experience with satellite communications has demonstrated that such systems can satisfy many military requirements for reliable, survivable, secure and cost effective telecommunications.

Satellites are the ideal, if not the only solution to problems of communicating with highly mobile forces deployed worldwide.

Satellites, if properly used, provide the needed geographically independent alternate to large, fixed ground installations.

For the past fifty years, the Navy has primarily used high frequency (HF) transmission as the principal method of sending messages. In the 1970s, an era when the HF spectrum is overcrowded, when "free" frequencies are at a premium, and when HF jamming techniques are highly sophisticated, the need for new and advanced long-range transmission methods becomes readily apparent.

Communications via satellite is a natural outgrowth of modern technology and the continuing demand for greater capacity and higher quality communications. Relatively recent technical developments have made satellite communications possible.

Although the communications facilities of the various military departments have generally been able to support their requirements in the past, predictable requirements indicate that large-scale improvements will have to be made to satisfy future needs of the Department of Defense. The usage rate of both commercial and military systems has increased by at least ten percent per year over the past fifteen years, and there appears to be general agreement that this trend will continue at an accelerated rate. Centralized control of military operations, with its accompanying reliability and security requirements, has generated demands for communications with greater capacity and for long-haul communications to previously

FREQUENCY	DESCRIPTION	ABBREVIATION
30GHz–300GHz	extremely high frequency	EHF
3GHz–30GHz	super high frequency	SHF
300MHz–3GHz	ultra high frequency	UHF
30MHz–300MHz	very high frequency	VHF
3MHz–30MHz	high frequency	HF
300kHz–3MHz	medium frequency	MF
30kHz–300kHz	low frequency	LF
3kHz–30kHz	very low frequency	VLF

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Figure 3-8.—Radio Frequency Spectrum.

inaccessible areas. Some of these requirements can be met only by sophisticated modulation techniques and wideband, long-distance transmissions for which satellite communications is the most promising means.

A Basic Satellite Communication System

A satellite communication system is one that uses earth-orbiting vehicles or satellites to relay radio transmissions between earth terminals. There are two types of communication satellites: active and passive. A passive satellite merely reflects radio signals back to earth. An active satellite, on the other hand, acts as a repeater; it amplifies signals received and then re-transmits them back to earth. This increases the signal strength at the receiving terminal compared to that available from a passive satellite.

A typical operational link involves an active satellite and two earth terminals. One station transmits to the satellite on a frequency called the up-link frequency, the satellite amplifies the signal, translates it to the down-link frequency, and then transmits it back to earth where the signal is picked up by the receiving terminal. This basic concept is illustrated by figure 3-9 which shows several types of earth terminals.

The basic design of a satellite communication system depends to a great degree upon the parameters of the satellite's orbit. In general terms an orbit is either elliptical or circular and its inclination is classified as inclined, polar or equatorial. A special type or orbit is a synchronous orbit, one in which the period of the orbit is the same as that of the earth.

The essential basic system components of an operational communication satellite system are (1) an orbiting vehicle with a communication receiver and transmitter installed and (2) two earth terminals equipped to transmit signals to and receive signals from the satellite. The design of the overall system determines the complexity
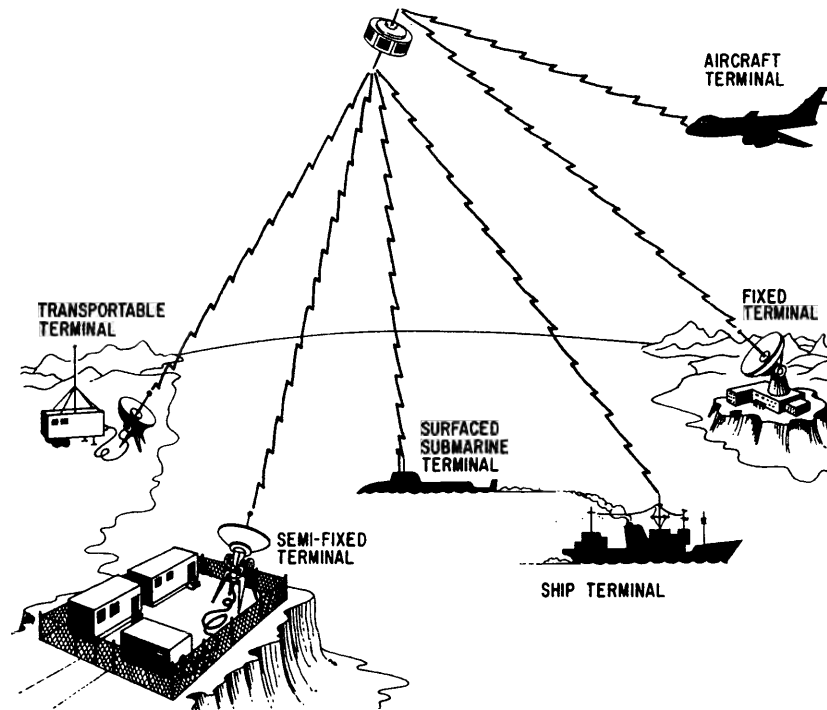

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Figure 3-9.—Satellite Communication System.

of the various components and the manner in which the system operates.

SATELLITE POWER SOURCES.—Early communication satellites were severely limited by the lack of suitable power sources; this, in turn, severely limited the output power of the satellite transmitter. The only source of power available within early weight restrictions was a very inefficient panel of solar cells without battery backup. A major disadvantage of this type of power source is that the satellite has no power when the satellite is in eclipse.

A combination of solar cells and storage batteries is a better prime power source for satellites. This is a practical choice at this time, even though the result is far from an ideal power source.

Although numerous nuclear power sources have been used in space for special purposes, the state of the art has not progressed sufficiently for nuclear power sources to be competitive with the solar cell-battery combination for synchronous communication satellites. With solar cells exposed to the sun continuously (and battery backup for eclipses), the solar cell-battery installations is lighter in weight, more efficient, and less costly than existing nuclear power sources.

SATELLITE ORIENTATION.—Satellite orientation in space is quite important for two reasons: continuous solar cell orientation and continuous antenna orientation. Since the primary source of power in most satellites is from solar cells, it is essential that the maximum number of the solar cells be exposed to the sun at all times. Moreover, for useful communications, the satellite antenna must be visible to appropriate earth terminals. Communication satellites use spin stabilization to meet these important requirements.

Spin stabilization operates on the principle that the direction of the spin axis of a rotating body tends to remain fixed in space. A natural example of spin stabilization is the effect of the earth's rotation in keeping its axis fixed in space. A satellite having a spin axis parallel to the earth's axis will maintain this position since both axis are fixed in space. Figure 3-10 illustrates the use of this principle with an equatorial orbit satellite to keep a doughnut-shaped antenna pattern pointing toward the earth.

Spin stabilization requires virtually no additional energy, once the system is in motion. A spin stabilized satellite is usually constructed like a flywheel with the heavier equipment mounted in the same plane and as close to the outside surface as possible.

After orbital injection, the radial jets are pulsed to initiate spinning. The satellite spin axis is oriented to the earth's axis by means of the axial jets, which are pulsed at the proper spin phase. The velocity jets, pulsed at the proper spin phase, provide orbit position and velocity correction. See figure 3-11.

In an effort to overcome the disadvantage of omnidirectional antennas, which radiate only a small amount of energy toward the earth, various techniques to achieve an earth-oriented antenna system have been developed and tested in space vehicles. The best system developed to date uses spin stabilization for orientation of the
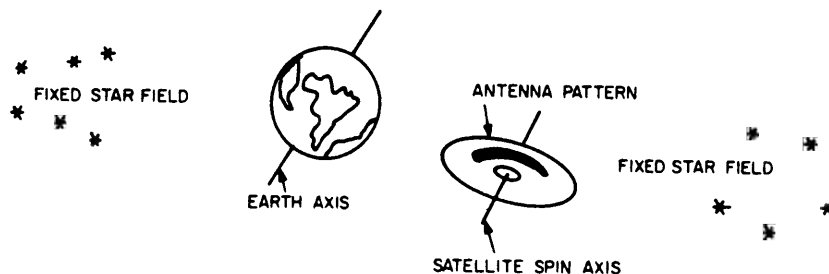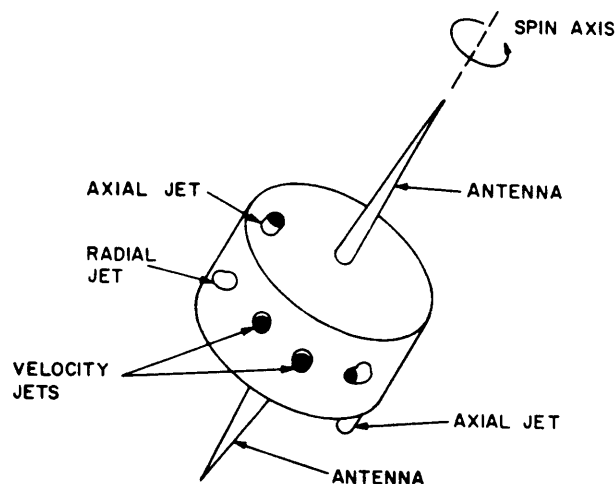

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Figure 3-10.—Spin-stabilized Satellite Antenna Pattern.

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Figure 3-11.—Spin-stabilized Satellite Controls.

satellite with a despun inner platform for mounting controllable antennas. The satellite is constructed in two parts with both parts having radial jets. The inner part is concentric with the outer part and contains the communication antennas and the communications package. The satellite is launched and injected into orbit in the usual manner. The whole satellite is spin stabilized using the outer radial jets. After the satellite is stablized with the desired orientation, the inner radial jets spin the inner part in the opposite direction to counter the initial spin. This results in a despun inner platform, which is stationary with respect to earth. The despun platform is oriented to such a position that the communication antennas point continuously toward the earth. This arrangement allows the use of high gain directional antennas to concentrate the majority of the radiated energy in the direction of the earth.

Earth Terminal Characteristics

Communication satellite earth terminals are generally located in areas remote from the actual users of these communications. This is necessary to minimize RF interference to the satellite communications. Characteristic of this remoteness is a need for interconnect links to permit communication flow to and from the

users of the satellite systems. These interconnect links are usually via telephone cables or microwave radio with normal terminal equipments. Earth terminals generally have a single large antenna, a highly sensitive receiver, a powerful transmitter, multiplex equipment, modulating-demodulating equipment, and telemetry equipment. There are four types of satellite terminals presently in use. They are the AN/FSC-9 (figure 3-12), the AN/MSC-46 (figure 3-13), the AN/TSC-54 (figure 3-14, and the AN/SSC-6 (figure 3-15) which is a shipboard type.

ANTENNAS.—Earth terminal antennas are highly directional, high-gain antennas capable of transmitting and receiving signals simultaneously. Generally, large, high-gain, parabolic antennas are used.

Three sizes of parabolic-type antennas are currently in use at earth terminals: the AN/FSC-9 uses a parabolic antenna 60 feet in diameter; the AN/MSC-46 uses a parabolic antenna 40 feet in diameter; and the AN/TSC-54 uses a cluster of 4 parabolic antennas, each 10 feet in diameter, which in combination are equivalent to a parabolic antenna 18 feet in diameter.

RECEIVERS.—All satellite communication earth terminals are equipped with specially designed, highly sensitive receivers. These highly sensitive receivers are required to overcome the down-link power limitations and to permit extraction of the desired communication information from the received signal. All of the terminals currently in use utilize specially designed preamplifiers mounted directly behind the antennas.

TRANSMITTERS.—All earth-terminal transmitters generated high-power signals for transmission to the communication satellites. The combination of high-powered transmitters are highly directional, high-gain antennas are necessary to overcome the up-link limitations and to ensure that the signals received by the satellite are strong enough to be detected by the satellite. Although various arrangements of functional components are possible in transmitters, all the transmitters presently in use at the earth terminals have the same general

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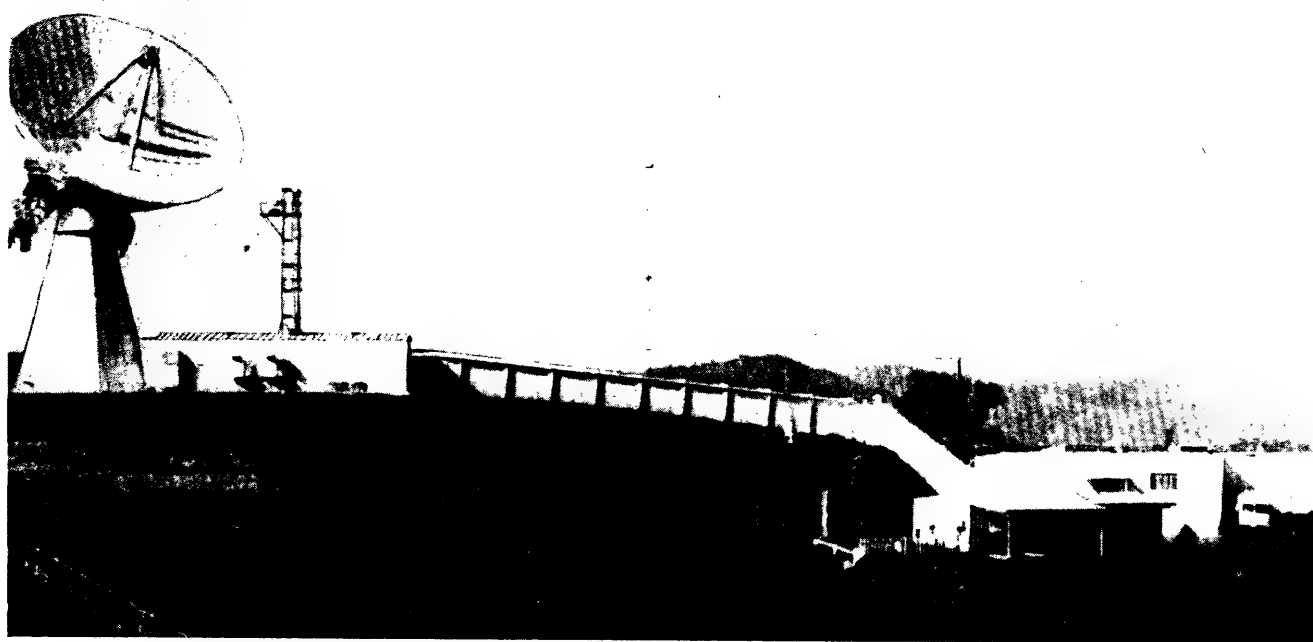
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Figure 3-12.—AN/FSC-9 Satellite Earth Terminal.

arrangements. Each transmitter has an exciter/modulator and a power amplifier. The modulator accepts the baseband input from the terminal equipment and modulates an IF carrier. The exciter translates the IF signal to the up-link frequency and amplifies it to the level required by the klystron of the power amplifier. The output power of the AN/FSC-9 is variable from 10 W to 20 kW; that of the AN/MSC-46 is variable from 100 W to 10 kW; and that of the AN/TSC-54 is variable from zero to 5 kW.

TELEMETRY EQUIPMENT.—Telemetry equipment is included in all communication satellite systems to permit monitoring of the operating conditions within the satellite. Telemetry can also be used for remote control of satellite operations, such as energizing axial jets for changing the spin axis of the satellite.

Applications of Satellite Communication

In the application of satellite communication resources to military communications, certain deployments will exploit to the maximum extent their versatility and capacity. Some of the applications are:

a. Defense Communication System (DCS) Long-Distance, Common-User Communication. This type of communication represents the normal employment of the satellite subsystem. This application provides additional high-capacity wide-band trunks for a variety of transmission modes and added flexibility for rerouting traffic.

b. Defense Communication System (DCS) Area, Common User Communication. Area communication supports large concentrations of forces engaged in operations encompassing a discrete remote area. Such service extends high-capacity, long-distance DCS trunks to a large number of potential users engaged in tactical operations.

c. Contingency Operation.—In this application the DCS facilities are extended to support a military operation or humanitarian
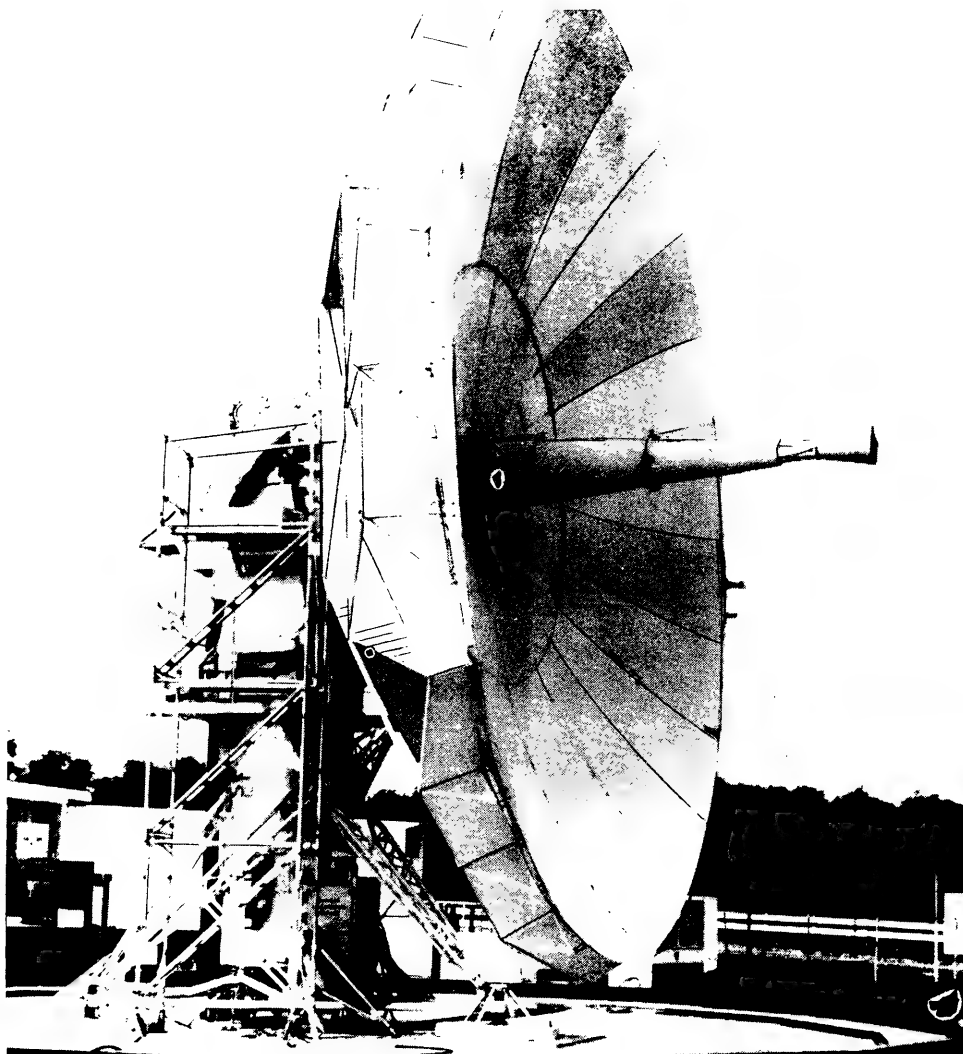
31.105

Figure 3-13.—AN/MSC-46 Antenna and Pedestal.

effort. In this connection, the capability of the satellite subsystem can be used to advantage to support rapid deployment and to furnish reliable long-distance trunking service within a minimum time.

d. Command and Control of Widely Deployed Forces.—High frequency communication to elements of widely deployed forces is difficult even under ideal propagation conditions. On the other hand, the capabilities of a satellite subsystem offer rapid, reliable communication between and among mutually supporting theater and fleet commanders. A

satellite subsystem also possesses the necessary flexibility for system configuration without loss of contact during sudden or frequent headquarters displacement.

e. Tactical Communications.—With the development of suitable antennas and equipments that can be installed in most types of ships and aircraft, satellite communications will be able to fill the requirements for various tactical communications, such as ship-to-ship, ship-to-aircraft, ship-to-shore-to-ship, and aircraft-to-ship. This type of communications

53

31.106
Figure 3-14.—AN/TSC-54 Satellite Communication Terminal.

will be more reliable and less subject to detection than methods presently in use.

f. Fleet Broadcast and Ship-to-Shore.—Present fleet broadcasts and ship-to-shore communications rely heavily upon HF for communication over extended distances. As with tactical communications, a satellite subsystem will be more reliable and less subject to detection. This will ensure reliable long-range links between major fleet units and naval communication stations ashore and will simultaneously enhance fleet security.

Advantages of Satellite Communications

Satellite communications offer unique advantages over conventional transmission for long-distance service. Satellite links are unaffected by the propagation abnormalities that interfere with HF radio, are free from the high attenuation of wire or cable facilities, and are capable of spanning long distances without the numerous intervening repeater stations which are required for line-of-sight or troposcatter links. They can furnish the greater reliability and flexibility of service needed to support a military operation.

CAPACITY.—Although existing commercial satellite communication systems are capable of handling hundreds of voice-frequency channels, the present operational military communication satellite system is limited to less than a dozen voice channels per earth terminal.

RELIABILITY.—Since propagation of communication satellite frequencies is not dependent upon reflection or refraction and is affected only slightly by atmospheric phenomena, the reliability of active satellite communication systems is limited only by the reliability of the equipment employed and the skill of the operating and maintenance personnel.

VULNERABILITY.—Within the present state of the art in rocketry, destruction of an orbiting vehicle is possible; however, destruction of a single communication satellite would be quite difficult and expensive. The cost would be excessive compared to the tactical advantage gained. It would be particularly difficult to destroy an entire multiple-satellite system such as the twenty-six random-orbit satellite system currently in use. The earth terminals offer a more attractive target for physical destruction, but they can be protected.

A high degree of invulnerability to jamming is afforded by the highly directional antennas at the earth terminals and by the wide bandwidth system which can accommodate sophisticated antijam techniques such as spread spectrum and frequency hopping.

FLEXIBILITY.—Almost all of the existing operational military satellite earth terminals are housed in transportable vans that can be loaded into cargo planes and flown to remote areas. With trained crews these terminals can be put into operation in a matter of hours. Therefore,
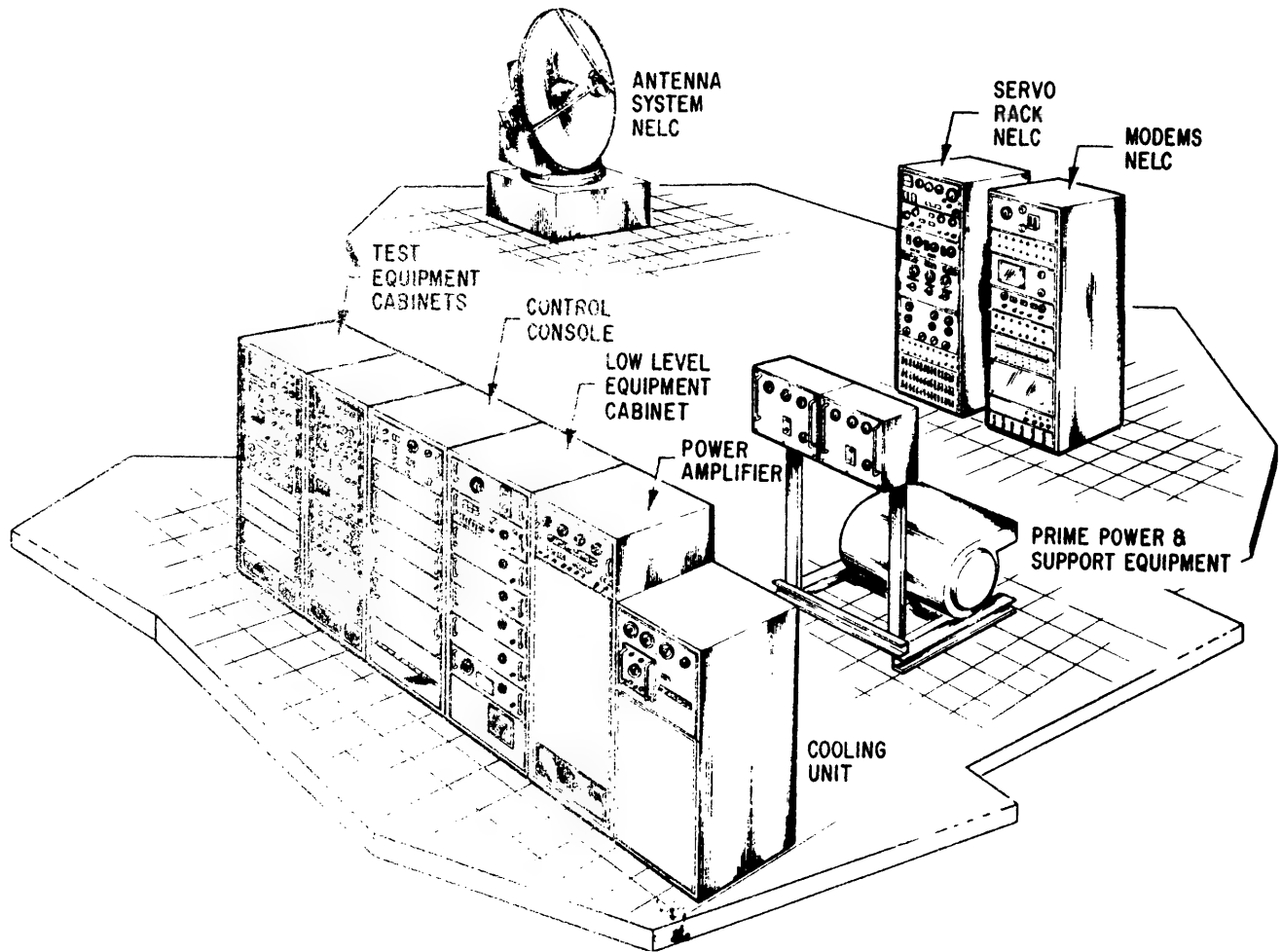
31.107

Figure 3-15.—AN/SSC-6 Shipboard Type Terminal.

direct long-haul communications can be established quickly to remote areas nearly anywhere in the free world.

Limitations

Limitations of a satellite communications system are determined by the satellite's technical characteristics and its orbital parameters. Active communication satellite systems are limited by satellite transmitter power on the down links and to a lesser extent by satellite receiver sensitivity on the up links. Communication satellites have also been limited by low-gain antennas.

SATELLITE TRANSMITTER POWER LIMITATIONS.—The amount of power available in an active satellite is limited by the weight restrictions imposed on the satellite. Early communication satellites were limited to a few hundred pounds because of launch-vehicle payload restraints. The only feasible power source consistent with the above weight limitation is the inefficient solar cell. Thus the RF power output is severely limited, and a relatively weak signal is transmitted by the satellite on the down link. The weak transmitted signal, further diminished by propagation losses, results in a very weak signal being available at the earth terminals. The level of signals received

from a satellite is comparable to the combination of external atmospheric noise and internal noise of standard receivers. Consequently, special techniques must be used to permit extraction of the desired communication information from the received signal. Large, high-gain antennas and special types of preamplifiers solve this problem, but add complexity and size to the earth terminal. Development of more efficient power sources and relaxation of weight restrictions will permit improved satellite performance and increased capacity.

SATELLITE RECEIVER SENSITIVITY.—Although powerful transmitters and highly directional antennas can be used at an earth station, the spherical wavefront of the radiated signal spreads as it travels through space. The satellite antenna intercepts only a small amount of this transmitted signal power and, because of its low gain, a relatively weak signal is received at the satellite receiver. Although the strength of the signal received on the up-link is not as critical as that received on the down-link, careful design of the RF stage of satellite receivers is required to achieve satisfactory operations. Development of stabilized high gain antennas and improved RF input stages in the receiver will make this problem less critical.

SATELLITE AVAILABILITY.—The availability of a satellite to act as a relay station between two earth terminals depends on the locations of the earth terminals and the orbital parameters of the satellite. All satellites, except those in a synchronous orbit, will be in view of any given pair of earth stations only part of the time. The length of time that a nonsynchronous satellite in a circular orbit will be in the zone of mutual visibility depends upon the height at which the satellite is circling. Elliptical orbits cause the satellite zone of mutual visibility between any two earth terminals to vary from orbit to orbit, but the times of mutual visibility are predictable. See figure 3-16 for an illustration of the zone of mutual visibility.
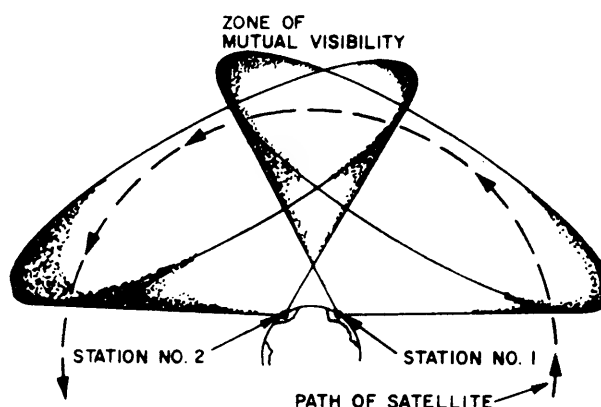
31.108

Figure 3-16.—Zone of Mutual Visibility.

FUTURE SATELLITE COMMUNICATIONS

In the future, when satellite communication technology becomes more advanced, it will be integrated into the present communication system and be fully compatible with other electronic systems and equipment. When this happens, the number of conventional transmitters and receivers aboard ships and shore stations can be reduced. Communications via satellite will augment existing communications as part of the overall system for the command and control of naval forces. Satellite communications will not replace all existing means of radio communications; however, it is a major step in modernizing Navy communications and will relieve the Navy of its total dependence on HF radio transmissions, ultimately reducing the need for many HF ground stations oversea.

The survivability of reliable communications for the command and control of our strategic nuclear forces is of paramount importance to the credibility of our deterrent. For this reason the Department of Defense is engaged in the development of new communications techniques and systems, including some that are space-based, to improve the survivability of our strategic communications against nuclear and electronic attack.

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If more information on satellite communications is desired, consult NAVELEX 0101,105.

ANTENNAS

As a CTM, you will be concerned primarily with receiving antennas and antenna arrays. Perhaps you have noticed when reading about antennas, that the discussion is usually written from the standpoint of antennas used with a transmitter. However, by a theorem called the reciprocity theorem, the electrical characteristics of a receiving antenna are the same as if the antenna were used for transmitting. Therefore, if it is necessary to find the electrical characteristics of a receiving antenna (i.e., radiation resistance, lobe patterns, etc.) the computations are performed in the same manner as though the antenna were used for transmitting. The basic concepts required for the consideration of antennas and transmission lines can be found in *Basic Electronics*, NAVPERS 10087.

When actually designing a receiving antenna the design criteria will be different from those used when designing a transmitting antenna. The difference in criteria stems from the fact that transmitting antennas are primarily designed to be "impedance matchers", while receiving antennas are not. A transmitting antenna is designed to provide the proper impedance matching to obtain the most efficient transfer of power at the transmitter output terminals. If the same antenna were used with a receiver, it would provide the most efficient coupling possible to transfer the energy from space to the input terminals of the receiver. However, this is not necessarily the most important consideration for a receiving system. For reception purposes, the primary consideration is usually to obtain the highest possible signal-to-noise ratio over the frequency range of the receiver.

As a result of the consideration just described, transmitting antennas must be carefully tuned, carefully coupled to the transmitter, and operated in a relatively narrow frequency band in order to achieve efficient operation. Receiving antennas do not have to be as carefully tuned and can generally operate over relatively broad frequency bands.

The most basic antenna unit is the half-wave antenna (dipole). Half-wave antennas are generally referred to as Hertz antennas, and are also known by many other names that describe or identify the type of feed (coupling) used.

Half-wave antennas have wide use in the Navy, both for transmitting and receiving. The different types of feed have been developed from the problems of power dissipation associated with the considerations of transmitting. Since these considerations are generally of little concern for receiving antennas, many of the variations offer little advantage over the basic design.

The directivity of a half-wave antenna is somewhat affected by polarization. The radiation field, or for purposes of reception, the area from which signals may be received, may be likened to a doughnut on a stick. (figure 3-17). In the case of a vertical half-wave antenna, the field exists fairly equally in all directions in a plane perpendicular to the axis of the antenna.

The presence of the ground (earth's surface) modifies the free-space directivity pattern, due to the reflection and absorption of the radiated wave from the antenna. Reflection takes place because the electromagnetic wave leaves the antenna at such angles that some of the radiation strikes the earth's surface at many points in space surrounding the antenna. The resultant radiation will be composed of two components - that reflected from the ground, and that arriving directly from the antenna. The reflected component will reinforce or cancel the direct component, depending on the phase relationship and the amplitude of the reflected wave. The phase relationship is a function of the height of the antenna above the ground, and the conductivity of the ground. The amplitude of the reflected component is largely a function of the conductivity of the ground. Therefore, the presence of ground distorts the free-space directivity pattern. The amount of distortion is dependent on the height of the antenna above ground and the conductivity of the ground.

A horizontal half-wave antenna in free-space will also have a doughnut-shaped field surrounding it. When in the presence of the ground, this doughnut-shaped field is also affected by the conductance of the ground and by the height of the antenna from ground.
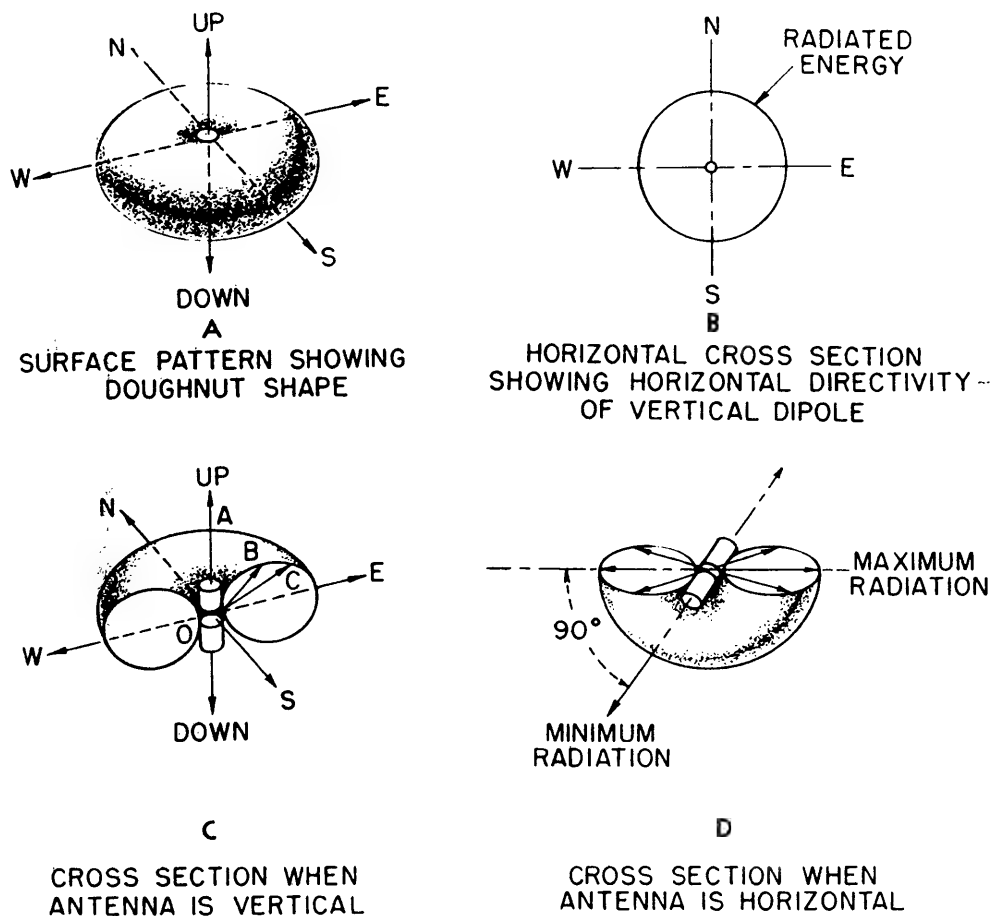
A
SURFACE PATTERN SHOWING
DOUGHNUT SHAPE

B
HORIZONTAL CROSS SECTION
SHOWING HORIZONTAL DIRECTIVITY
OF VERTICAL DIPOLE

C
CROSS SECTION WHEN
ANTENNA IS VERTICAL

D
CROSS SECTION WHEN
ANTENNA IS HORIZONTAL

1.255

Figure 3-17.—Radiation Pattern of a Dipole.

End-Fed Half-Wave Antenna

Before World War II, the end-fed half-wave (Zepp) antenna was widely used in communications systems. Its popularity arose from the fact that it is automatically matched to its feeder at the feed point for all even-order harmonics.

One disadvantage is that it is very difficult to eliminate all radiation from its feeders, therefore the over-all efficiency of the antenna system is lowered. For radiating a relatively broad band of frequencies that are not related harmonically, the feed line will not be matched to the transmitting source; hence reduced power output will result. Furthermore, feeder-current unbalance will result in increased radiation loss from the feeder. Thus, this type of antenna system is useful only for radiating the resonant frequency and a very narrow band on either side of the carrier.

Center-Fed Half-Wave Antenna

A tuned transmission line may be used to feed a half-wave antenna at its center. When this arrangement is used, it is called a TUNED DOUBLET (also called a center-fed Zepp or current-fed Zepp). The radiation resistance of the antenna is lowest at the point where the feeders are connected. This condition is exactly opposite to the condition existing when an end-fed half-wave antenna is used.

If the electrical lengths of the feeders are equal, incorrect antenna length or operating frequency will not unbalance the feeder currents as it does in the case of the end-fed half-wave antenna. Instead, the standing waves on the feeders move symmetrically along both feeders and complete balance is maintained. Thus, it is possible to use the tuned doublet over a comparatively wide range of frequencies without undue losses or radiation from the feeders. Furthermore, the inherent unbalance of the feeders found in the end-fed half-wave antenna is not present in the tuned doublet because the two feeder wired are equally loaded.

The tuned doublet operates as a current-fed system on its fundamental frequency and as a voltage-fed system on even harmonics. When this antenna is operated on its second harmonic, it is known as a FRANKLIN COLINEAR ARRAY.

Quarter-Wave Antennas

The usual MARCONI antenna is a grounded, vertical quarter-wave antenna. The vertical portion acts like one-half of a half-wave antenna, and the ground acts like a mirror-image to supply the missing quarter-wave section. Figure 3-18 illustrates the standing waves of current and voltage as they exist on a MARCONI antenna. The current maximum is at the base (feed point) and therefore the antenna is current-fed, that is, fed at a point of low impedance. For a properly tuned antenna, the radiation resistance is approximately 36 ohms.

A vertical-grounded antenna must be an odd number of quarter-wavelengths long if the current maximum (low impedance) is to occur at the base. For example, if the antenna is less than a quarter-wavelength long, it will be capacitive at the base, and a coil must be added in series at this point to make it resonant. If it is more convenient, the same result can be accomplished by effectively adding a capacitive effect (top loading) at the top of the antenna. If the antenna is slightly more than a quarter-wavelength long, the input at the base will be inductive, requiring the addition of a series capacitor near the feed point to bring the antenna into resonance.

The radiation resistance (and efficiency) of the Marconi antenna decreases as the physical
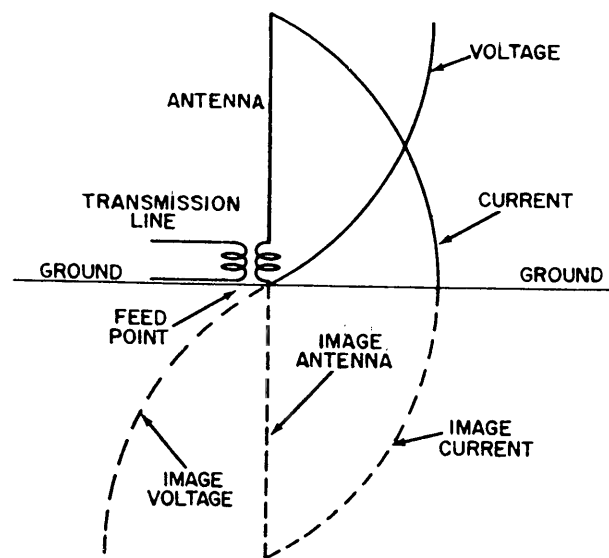
13.35

Figure 3-18.—Marconi Antenna & Waveforms of Current & Voltage.

length of the antenna is reduced. A reduction in physical length also affects the match to the transmission line.

Two types of $\frac{\lambda}{4}$ antennas used by the Navy for communication in a portion (60 to 80 MHz) of the VHF range are the ground plane antennas shown in figure 3-19. Navy type 66015 is shown in figure 3-19A. Four horizontal rods are used for the ground plane and a vertical rod of the desired length is used as a $\frac{\lambda}{4}$ radiator.

The Navy type 66016 (fig. 3-19B) is similar to the Navy type 66015, except that only two horizontal rods are used for a ground plane. This antenna is designed for submarine use.

Sleeve Antenna

The HF sleeve antenna is a variation of either the basic quarter-wave or half-wave antennas, depending upon the frequency range to be covered. In its basic configuration, the sleeve is broadbanded, vertically polarized, and omnidirectional. The sleeve antenna illustrated in figure 3-20 consists of two sections: a grounded lower section and an ungrounded upper section. The over-all height of the antenna is approximately one-quarter wavelength at the

A NAVY TYPE 66015

B NAVY TYPE 66016
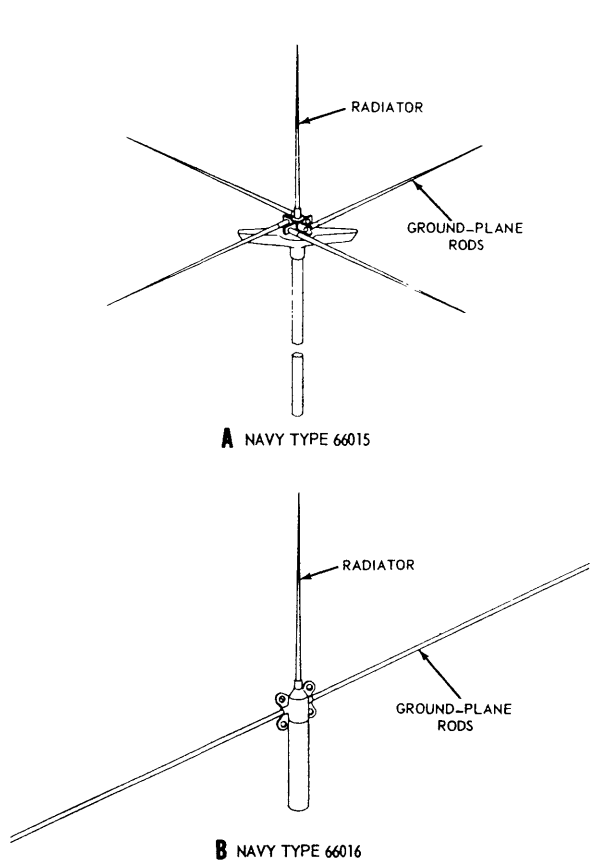
25.206

Figure 3-19.—Navy-type Ground-plane Antennas.

Figure 3-20.—Sleeve Antenna.   13.40

lowest operating frequency. The lower section is a wooden structure approximately one-half the height of the upper section with ten parallel wires distributed along each side. The transmission line is connected through a transformer to the junction of the base and the upper section. The nominal impedance of the sleeve antenna is 50 ohms, operating on a frequency ratio of 3 to 1 (e.g., if the antenna is cut to 12 MHz, it will effectively cover 4 to 36 MHz). The sleeve antenna is installed over a ground radial system consisting of 120 wires at least one-quarter wavelength long at the lowest operating frequency. The radiation pattern may be altered to provide a directional high-gain pattern by the use of a reflector screen or a combination of a reflector screen and a director.

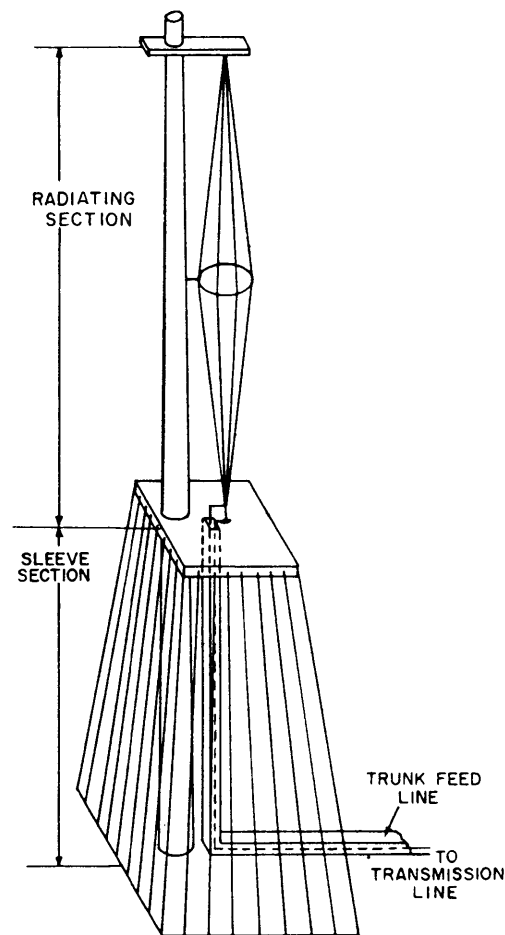The sleeve has two inherent advantages. First, it is fed above ground level, lessening snow accumulation problems and RF hazards to personnel. Second, it presents a relatively small electrical obstruction; that is, its influence on other antennas is not as severe as with other types.

The power handling capability of sleeve antennas averages 30 kw with a maximum of 50 kw.

Conical Monopole Antenna

Conical monopoles are used extensively in HF Navy communications. They were developed to fulfill a need for efficient broadband, vertically-polarized, omnidirectional antennas that are compact in size. These antennas are in

the shape of two truncated cones connected base-to-base. The basic conical monopole configuration shown in figure 3-21 is composed of equally spaced wire-radiating elements arranged in a circle around an aluminum center-tower. Usually the radiating elements are connected at the top and bottom discs; however, some conical monopole configurations have radiating elements terminated at the waist disc rather than the top disc.

The coaxial transmission line is terminated at the bottom disc in a terminal assembly. The transmission line is connected directly to the antenna with a characteristic impedance of

about 50 ohms. Most of these antennas used in transmitting applications are designed for 40 kw average power operation. An antenna designed to cover the 7 to 28 MHz band typically has a height of about 7.3 meters (24 feet). The ground radial system used with this antenna is basically the same as that of the sleeve antenna.

The conical monopole antenna has a low angle of radiation (approximately 10 degrees). At the higher frequencies, the lower cone section radiates, and the effect of the top section is to radiate the signal out at a low angle. In operation at low frequencies, the conical monopole is similar to a low Q (low gain) vertical antenna.

The dimensions shown in figure 3-21 depict lengths and diameters in feet when the frequency is in Megahertz. These dimensions should be determined for the lowest frequency to be used on the antenna.
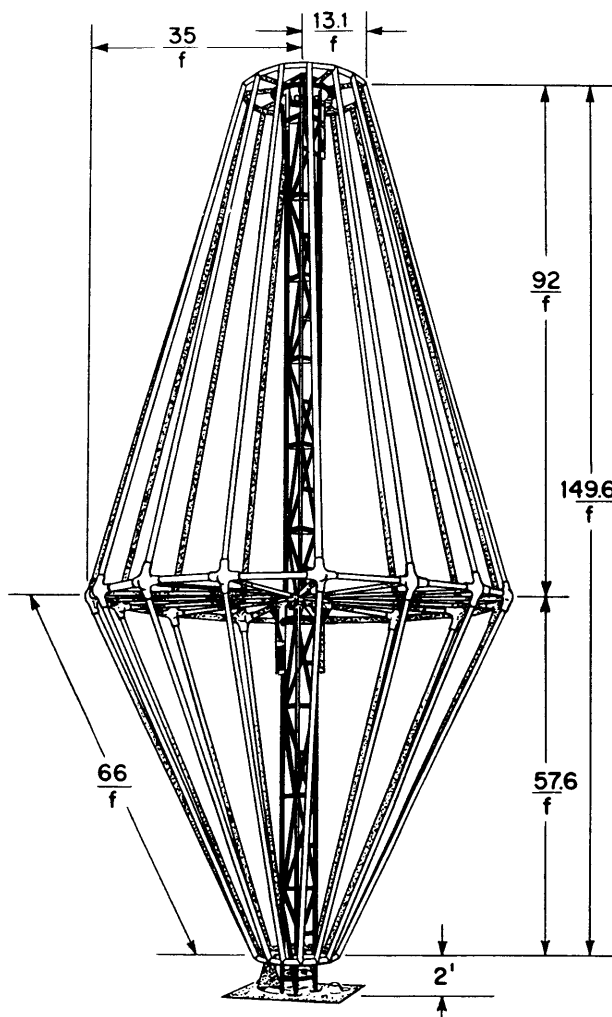
Long-Wire Antennas

Long-wire, or multiple-wavelength antennas have directional characteristics that may be used to advantage when a directional pattern is desired. Figure 3-22 illustrates how the major lobes make smaller wave angles with their respective antennas as the length of the antenna is increased. For the $\lambda/2$ antenna, the wave angle (Φ), is 90° ; for the λ antenna, Φ is 54°: for the $\frac{3}{2}\lambda$ antenna, Φ is 42°; for the 2 λ antenna, Φ is 36°; and for the 5 λ antenna, Φ is 22.5°. The graph gives the radiation angle of the main lobes with respect to the antenna axis for various lengths of the antenna.

Tilting the antenna from the horizontal position (1) (figure 3-23), to position (2), increases the transmission distance and low angle radiation from A to B and decreases these characteristics from C to D. Note that the direction of increased radiation is the same general direction as that of the downward tilt of the antenna.

Wave (Beverage) Antenna

The wave antenna is a horizontal long-wire antenna one or more wavelengths long and terminated at one end in its characteristic impedance (approximately 500 ohms). Generally, by using poles, this type of antenna is suspended about 3 to 6 meters (10 to 20 feet)

25.214
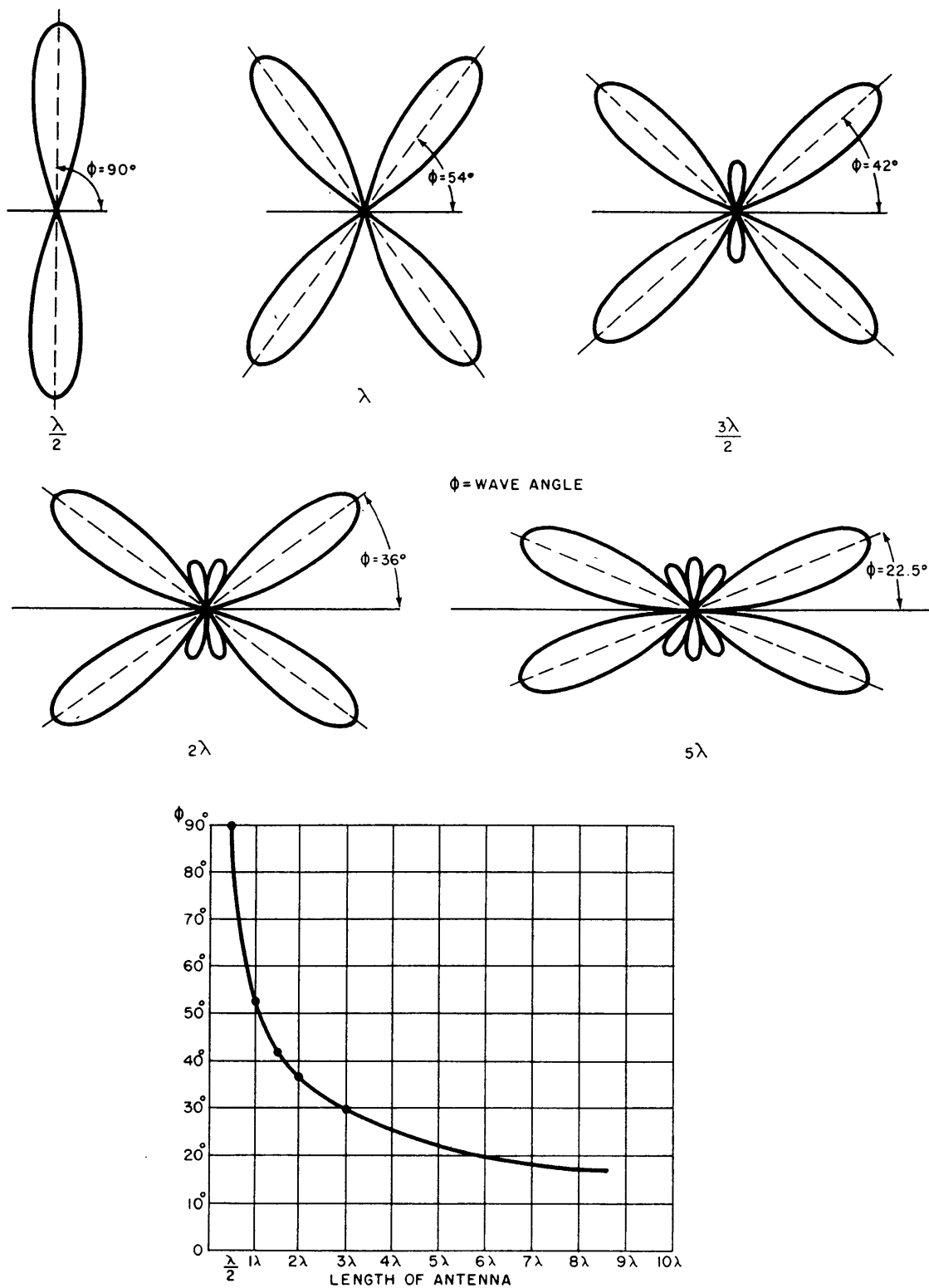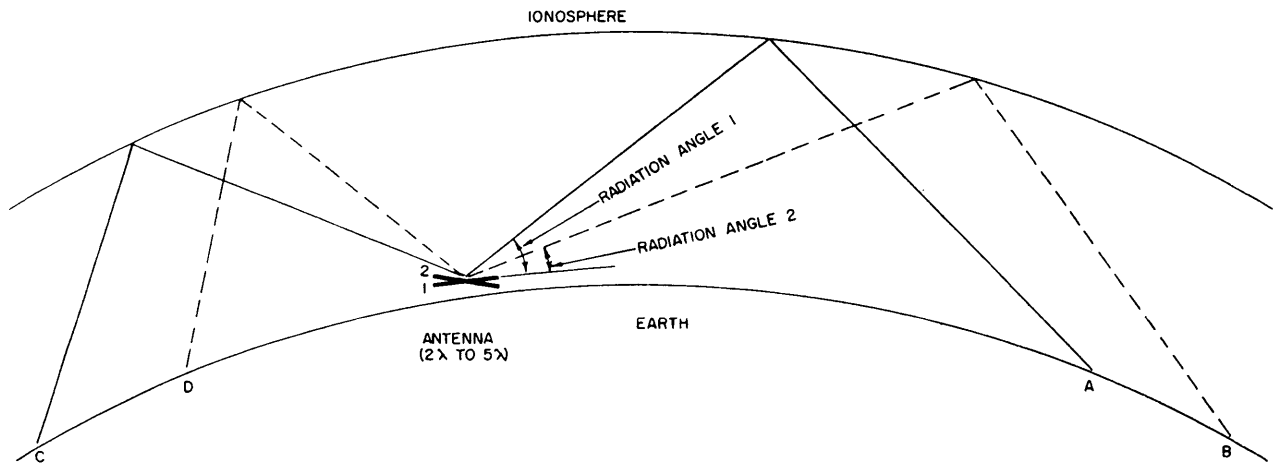
Figure 3-21.—Conical Monopole Antenna Dimensions.

Figure 3-22.—Free-Space Radiation Patterns of Long-Wire Antennas.   25.207

Figure 3-23.—Effect of Antenna Tilt.

25.208

from the ground and is terminated to ground in its characteristic impedance at the end nearest the transmitter (when the antenna is used for receiving). The antenna may be considered a one-wire transmission line with a ground return. Because of its termination, the antenna is nonresonant and may be used for the reception of several different frequencies without too much variation in directivity. Because the ground losses are high, this type antenna is not very efficient for transmitting, but is often used for receiving.

Vee Antenna

A Vee antenna is a bidirectional antenna widely used in military and commercial communication applications. It is made up of two long-wire antennas arranged in the form of the letter "V" and fed 180° out of phase at the apex, AC, as shown in figure 3-24. If the length of the long-wire antenna is increased, more power is concentrated near the axis of the wire. Because the Vee antenna is a combination of two long-wire antennas, the same reasoning may be applied to the Vee antenna as is applied to long-wire antennas.

Looking at figure 3-24 again, we see that the lobes on leg AB are labeled 1, 2, 3, and 4; the lobes on leg CD are labeled 5, 6, 7, and 8. When the proper waveangle (Φ) betwen AB and CD is chosen, lobes 1, 8, 3, and 6 combine to produce

the resultant pattern. This combination of two major lobes from each leg results in the formation of two stronger lobes that lie along the line that bisects angle Φ. The fields radiated at lobes 2, 4, 5, and 7 tend to cancel; this is also true of the minor lobe radiations.

The graph in the figure indicates the relationship of the apex angle in degrees and the leg lengths in wavelengths for maximum gain. The graph also shows the gain of Vee antennas of various leg-lengths over a half-wave antenna at the same height above ground.

From the graph it may be seen that the apex angle decreases with an increase in leg-length.

The wave angle for an antenna one-half wavelength above ground also decreases with an increase in L (leg-length).

If the legs of a Vee antenna are six or more wavelengths long, there is only a slight change in the apex angle required as the legs are lengthened still more. However, because the beam is narrower, orientation becomes increasingly critical. An error of a few degrees, in laying out the antenna, may result in a considerable loss of signal strength at the receiving station. Extreme care must therefore be used in laying out a high-gain Vee antenna. If the exact bearing of the receiving station is not known, or if precision surveying equipment is not available, better results can often be obtained by shortening the antenna to produce a
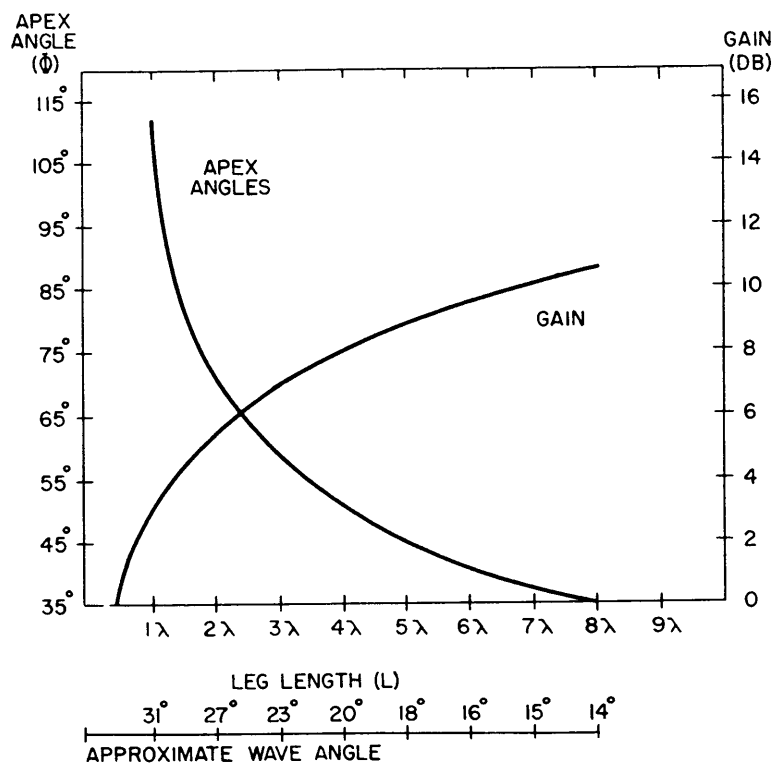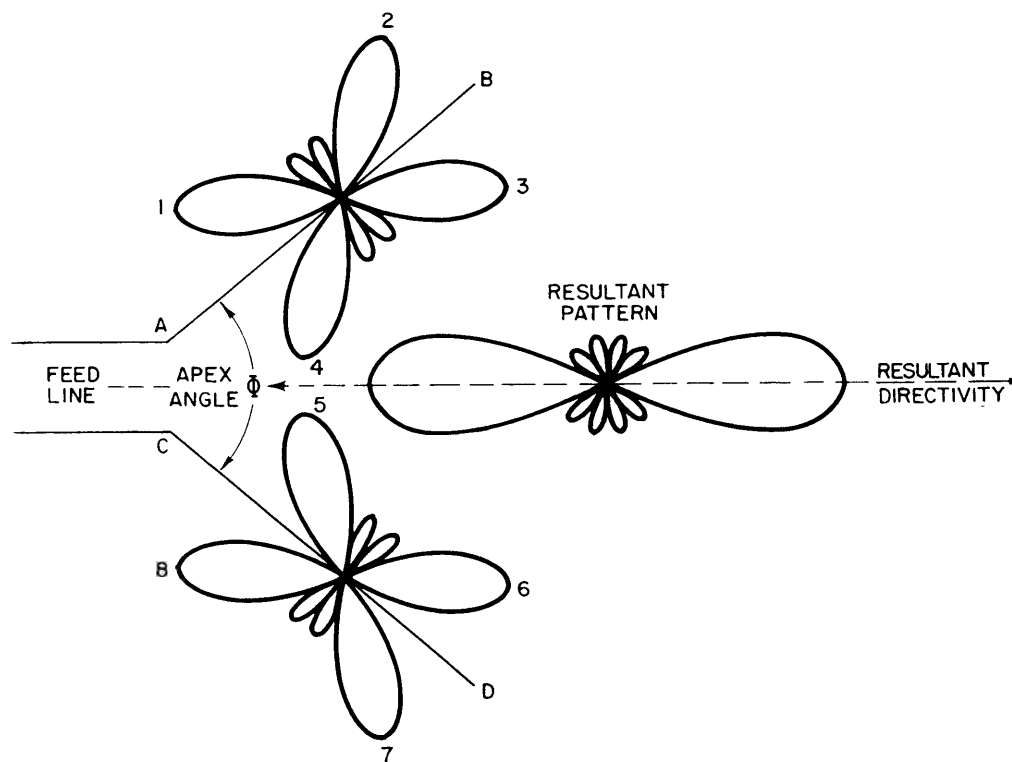
Figure 3-24.—Vee Antenna & Graph of Apex Angle Versus Wavelength for Maximum Gain.   25.210

wider radiation pattern. The Vee antenna may be tilted downward to increase the low-angle radiation from the low end. On a sloping site, the plane of the Vee antenna should be made parallel with the ground, with the open end pointing down the slope.

The Vee antenna can be made to develop more gain by placing a second Vee one-half wavelength above the first. The planes containing the antennas are parallel. This system is called STACKING. The second antenna is fed from the first through a line that is transposed, so that the corresponding legs of the two Vee antennas are in phase. Likewise, a broadside arrangement, forming a "W", may be used to increase the gain.

The Vee antenna can be made to develop a unidirectional pattern in the direction of the open end of the "V" by terminating the free end of each leg in the proper resistance (between 400 and 800 ohms) to ground. The terminating resistors may be connected to a counterpoise. The resistors should be of the non-inductive type and should be capable of dissipating approximately one-half of the power fed to the antenna. The exact value of the terminating resistance is determined by experiment. The value that gives the lowest standing-wave ratio is chosen.

Another method of making a Vee antenna unidirectional is to place a second antenna one-quarter wavelength behind the first, forming, in effect, one Vee within another. The two antennas are then fed 90° out of phase.

The Vee antenna may be fed by means of a 600 ohm resonant line attached to the apex of the V. When a nonresonant line is used, a match may be effected by means of a quarter-wave matching stub.

Half-Rhombic Antenna

The half-rhombic antenna is a special form of the long-wire antenna. It is sometimes called the inverted Vee or tilted-wire antenna. A half-rhombic antenna designed for unidirectional radiation is shown in figure 3-25. The maximum
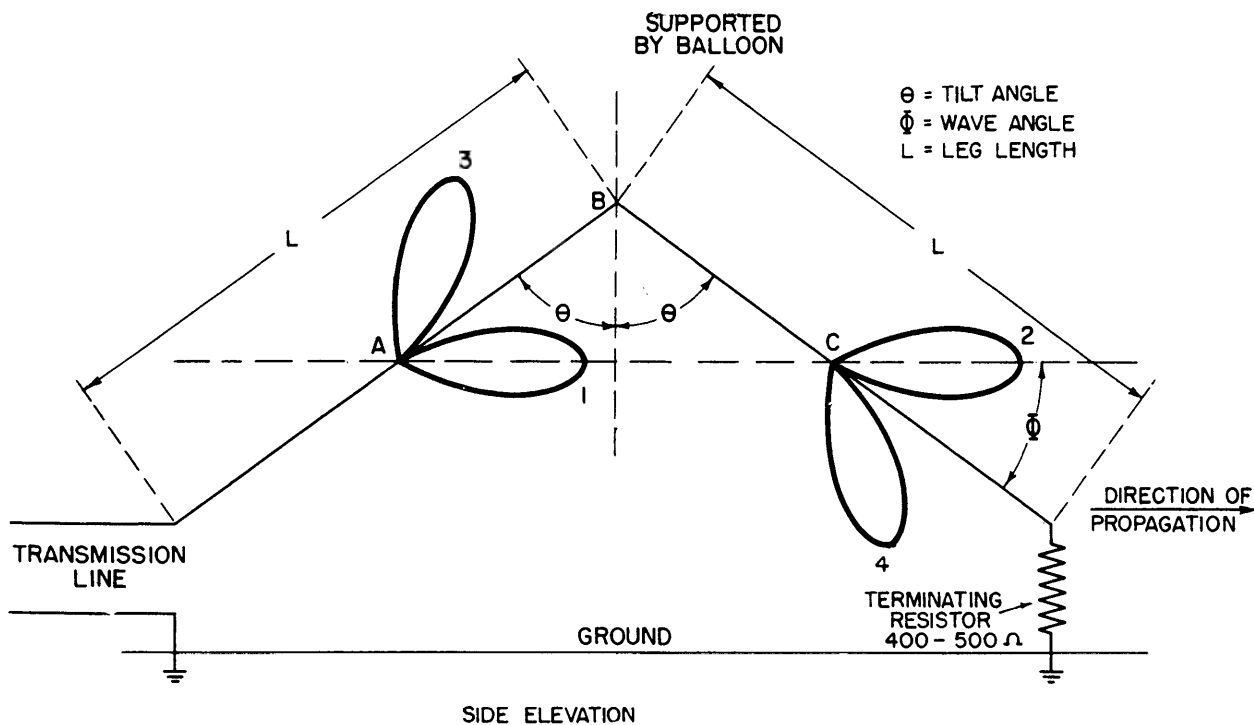

Figure 3-25.—Half-Rhombic Antenna.

25.211

field intensity is radiated in the direction of the terminating resistor. For reception, maximum signal strength is produced at the receiver when RF energy arrives by way of the terminated end of the antenna.

In order that lobes 1 and 2 may properly combine in the desired direction of propagation, the distance, AC, is approximately a half wave-length less than distance ABC. This arrangement causes the fields radiated at lobes 1 and 2 to be additive in the direction of propagation. The fields radiated at lobes 3 and 4 cancel.

The length of a half-rhombic antenna, for operation at about 4 MHz, from the imput to the antenna to the terminating resistor is approximately 389.5 meters (1278 ft.). The altitude of point B is approximately 112.5 meters (369 ft.).

Full-Rhombic Antenna

The rhombic (or diamond) antenna is another form of long-wire antenna. Although the half-rhombic has certain advantages over some of the other long-wire antennas, it also has certain major disadvantages, such as difficulty in construction and termination. The full-rhombic is one of the better antennas (where adequate space is available for its erection) for obtaining maximum gain in the desired direction. For reception, it provices a good signal-to-noise ratio; and, for transmission, it provides a relatively low angle of radiation (of the order of from 0° to 20°). The full-rhombic antenna is widely used for both transmission and reception at Navy antenna "farms": that is, selected localities where large numbers of antennas are installed.

The full-rhombic antenna may be considered as two half-rhombics in a horizontal plane, with one end connected to a common terminating resistor, and the other to a balanced receiver or transmitter through a suitable transmission line. A schematic diagram of a full-rhombic is shown in figure 3-26.

The terminating resistance is at the end of the antenna toward the distant receiver in the case of a transmitting antenna, and at the end of the antenna toward the distant transmitter in the case of a receiving antenna. The input impedance for this type of antenna is essentially constant over a wide range of frequencies.

The gain of this type of antenna depends on the dimensions of the antenna with respect to the wavelength of the operating frequency. The gain of a rhombic antenna is approximately 20 times that of a half-wave dipole when each leg is 2 wavelengths long. When each leg is 4 to 5 wavelengths long, the gain is approximately 40 times that of a dipole. Radiation is maximum in the direction of the terminating resistor, and is greatly reduced in all other directions.

A rhombic antenna often has two or three conductors in each leg. The conductors are separated by a distance of several feet at the side poles and are brought together at the terminating and transmission end supports. A more nearly constant input impedance is thereby maintained over a relatively wide frequency range.

To obtain a unidirectional pattern, the correct terminating impedance must be used.

Double-Ended Rhombic

In order to make full use of the bidirectional potential of a full-rhombic receiving antenna, it is a common practice to double-end the rhombic. When double-ending the rhombic, each end is terminated in its characteristic impedance (700 to 800 ohms) and transmission lines are connected to each end of the antenna through matching devices. By this manner of double-ending, the antenna may be used to receive two transmissions from opposite directions. Each unidirectional pattern can be used independently by the use of two separate transmission lines.

Nested Rhombic

The standard three-wire rhombic is widely used in communications in a "nested-pair" configuration. In this type of installation, a smaller, higher frequency three-wire rhombic is placed within the periphery of a larger, lower frequency rhombic. For a typical "nested pair"
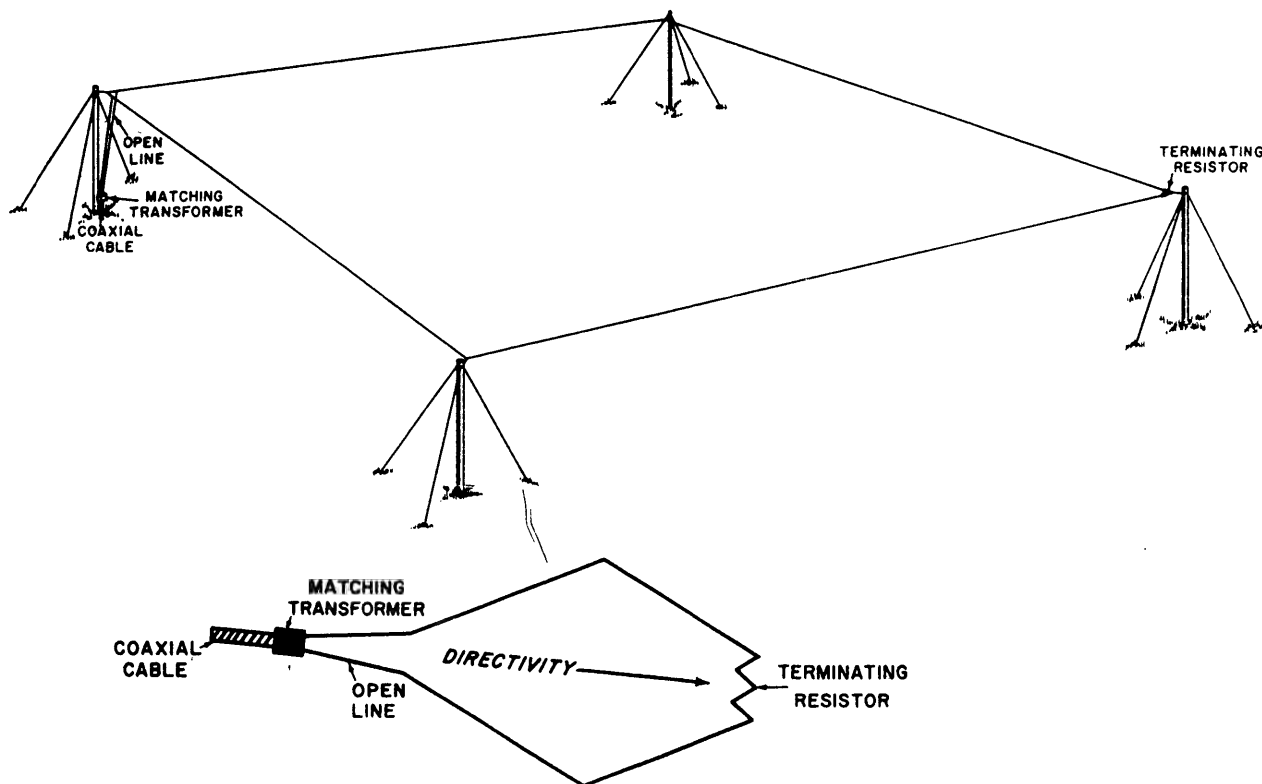
34.3

Figure 3-26.—Rhombic Antenna.

as shown schematically in figure 3-27, the inner rhombic might be designed for operation in the 10 to 28 MHz range; the outer for the 4 to 10 MHz range. The two rhombics are not connected together physically or electrically; however, both are connected to a common feed (rear) pole. Both antennas can be used in the selection of operating frequencies. The principal advantages of the "nested" configuration are reduced installation costs and more effective utilization of land.

End-Fire Antenna Array

The end-fire antenna array is so named because the principal radiation is off the ends of the array; that is, the radiation is maximum in the plane of the elements. This array may be contrasted with the broadside array in which maximum radiation is perpendicular to the plane of the elements.

A simple end-fire array employing two vertical half-wave antennas spaced $\frac{\lambda}{2}$ wavelength apart and fed 180° out of phase is shown in figure 3-28. Because the two antennas are $\frac{\lambda}{2}$ wavelengths apart and fed 180° out of phase, radiated energy will reinforce along line 1-2 in the plane of the antennas. Likewise, radiated energy is cancelled along line 3-4, broadside to the antennas.

If the spacing of the antennas is reduced to $\frac{\lambda}{4}$ wavelength, and the excitation of A lags that of B by 90°, a cardioid (heart-shaped) pattern is produced, as illustrated in figure 3-29.

Log-Periodic Antenna

An antenna arranged so that the electrical length and spacing between successive elements causes the input impedance and pattern to be repeated periodically with the logarithm of the
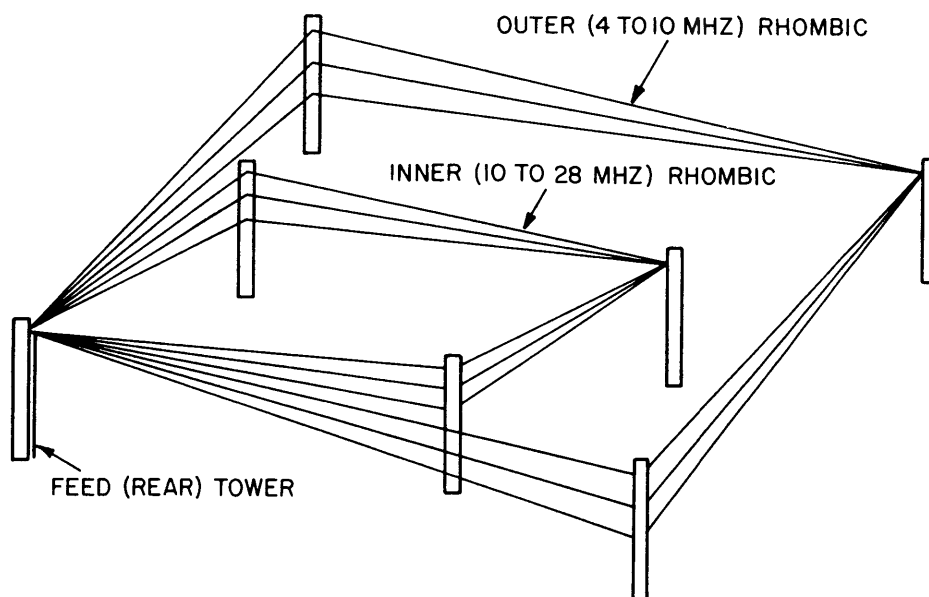
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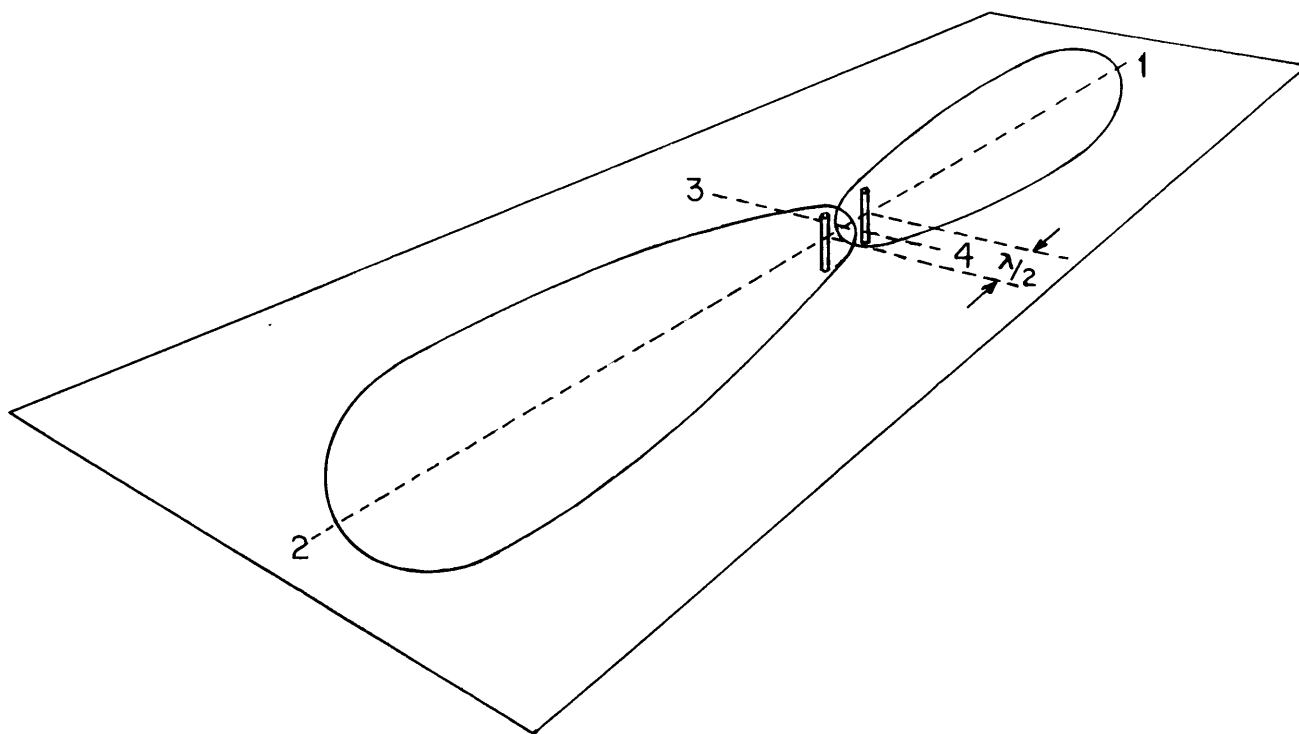1.388

Figure 3-27.—Nested Rhombic Configuration.

93.28

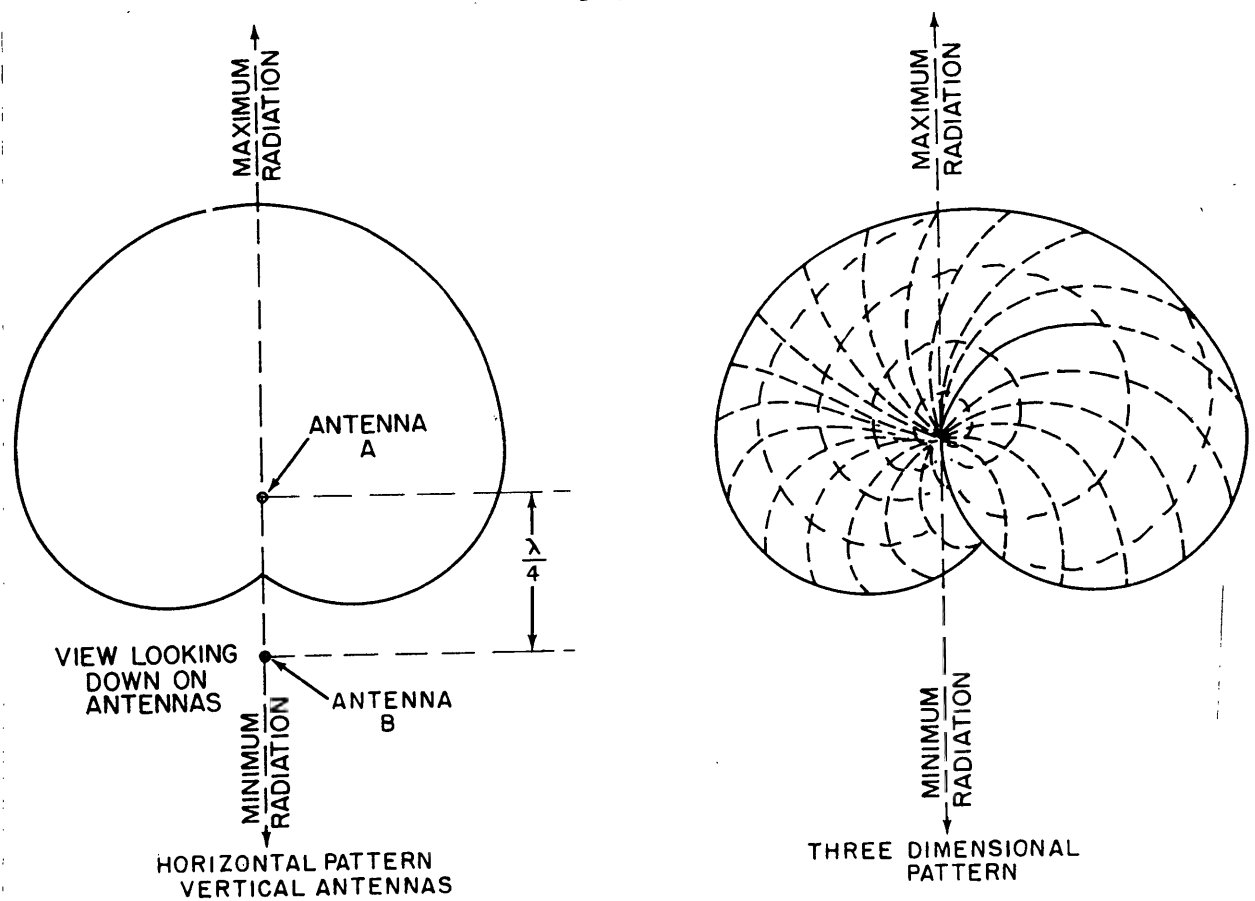Figure 3-28.—End-Fire Array with Half-Wave Spacing.

388

25.233

Figure 3-29.—End-Fire Array with Quarter-Wave Spacing.

driving frequency is called a log-periodic antenna (LPA). Both fixed-azimuth and rotatable LPA's are widely used in naval communications. Figure 3-30 illustrates two LPA's combined in a Vee formation to form a rotatable VLPA. Combining LPA's in this manner increases directivity and gain. Close inspection of the antenna in figure 3-30 will reveal that as the lengths of the elements increases, the spacing between successive elements also increases.

In an ideal log-periodic antenna, this repetition is scaled to vary with the logarithm of the frequency. For purposes of explaining the theory of operation of log-periodic antennas, the log-periodic dipole array in figure 3-31 will be used.

In this figure, assume that you have constructed a dipole antenna with dimensions equal to the longest pair of elements. Next to it you construct another dipole antenna resonant at some multiple of the original dipole resonant frequency. The elements are naturally shorter. Continue constructing dipole antennas which are resonant at increasing multiples of the basic frequency. If the dipoles are placed parallel to each other so that their tips are lined up as in the figure, the spacing between adjacent pairs will follow the same ratio as the lengths of the adjacent pairs.

If this analogy is modified so that the adjacent dipoles vary in size with the logarithm of the frequency, the same spacing relationship holds true, and the electrical properties of the antenna structure repeat periodically with the logarithm of the frequency. Since it is not physically possible to decrease the size of the

field intensity is radiated in the direction of the terminating resistor. For reception, maximum signal strength is produced at the receiver when RF energy arrives by way of the terminated end of the antenna.

In order that lobes 1 and 2 may properly combine in the desired direction of propagation, the distance, AC, is approximately a half wave-length less than distance ABC. This arrangement causes the fields radiated at lobes 1 and 2 to be additive in the direction of propagation. The fields radiated at lobes 3 and 4 cancel.

The length of a half-rhombic antenna, for operation at about 4 MHz, from the imput to the antenna to the terminating resistor is approximately 389.5 meters (1278 ft.). The altitude of point B is approximately 112.5 meters (369 ft.).

Full-Rhombic Antenna

The rhombic (or diamond) antenna is another form of long-wire antenna. Although the half-rhombic has certain advantages over some of the other long-wire antennas, it also has certain major disadvantages, such as difficulty in construction and termination. The full-rhombic is one of the better antennas (where adequate space is available for its erection) for obtaining maximum gain in the desired direction. For reception, it provices a good signal-to-noise ratio; and, for transmission, it provides a relatively low angle of radiation (of the order of from 0° to 20°). The full-rhombic antenna is widely used for both transmission and reception at Navy antenna "farms": that is, selected localities where large numbers of antennas are installed.

The full-rhombic antenna may be considered as two half-rhombics in a horizontal plane, with one end connected to a common terminating resistor, and the other to a balanced receiver or transmitter through a suitable transmission line. A schematic diagram of a full-rhombic is shown in figure 3-26.

The terminating resistance is at the end of the antenna toward the distant receiver in the case of a transmitting antenna, and at the end of the antenna toward the distant transmitter in the case of a receiving antenna. The input impedance for this type of antenna is essentially constant over a wide range of frequencies.

The gain of this type of antenna depends on the dimensions of the antenna with respect to the wavelength of the operating frequency. The gain of a rhombic antenna is approximately 20 times that of a half-wave dipole when each leg is 2 wavelengths long. When each leg is 4 to 5 wavelengths long, the gain is approximately 40 times that of a dipole. Radiation is maximum in the direction of the terminating resistor, and is greatly reduced in all other directions.

A rhombic antenna often has two or three conductors in each leg. The conductors are separated by a distance of several feet at the side poles and are brought together at the terminating and transmission end supports. A more nearly constant input impedance is thereby maintained over a relatively wide frequency range.

To obtain a unidirectional pattern, the correct terminating impedance must be used.

Double-Ended Rhombic

In order to make full use of the bidirectional potential of a full-rhombic receiving antenna, it is a common practice to double-end the rhombic. When double-ending the rhombic, each end is terminated in its characteristic impedance (700 to 800 ohms) and transmission lines are connected to each end of the antenna through matching devices. By this manner of double-ending, the antenna may be used to receive two transmissions from opposite directions. Each unidirectional pattern can be used independently by the use of two separate transmission lines.

Nested Rhombic

The standard three-wire rhombic is widely used in communications in a "nested-pair" configuration. In this type of installation, a smaller, higher frequency three-wire rhombic is placed within the periphery of a larger, lower frequency rhombic. For a typical "nested pair"
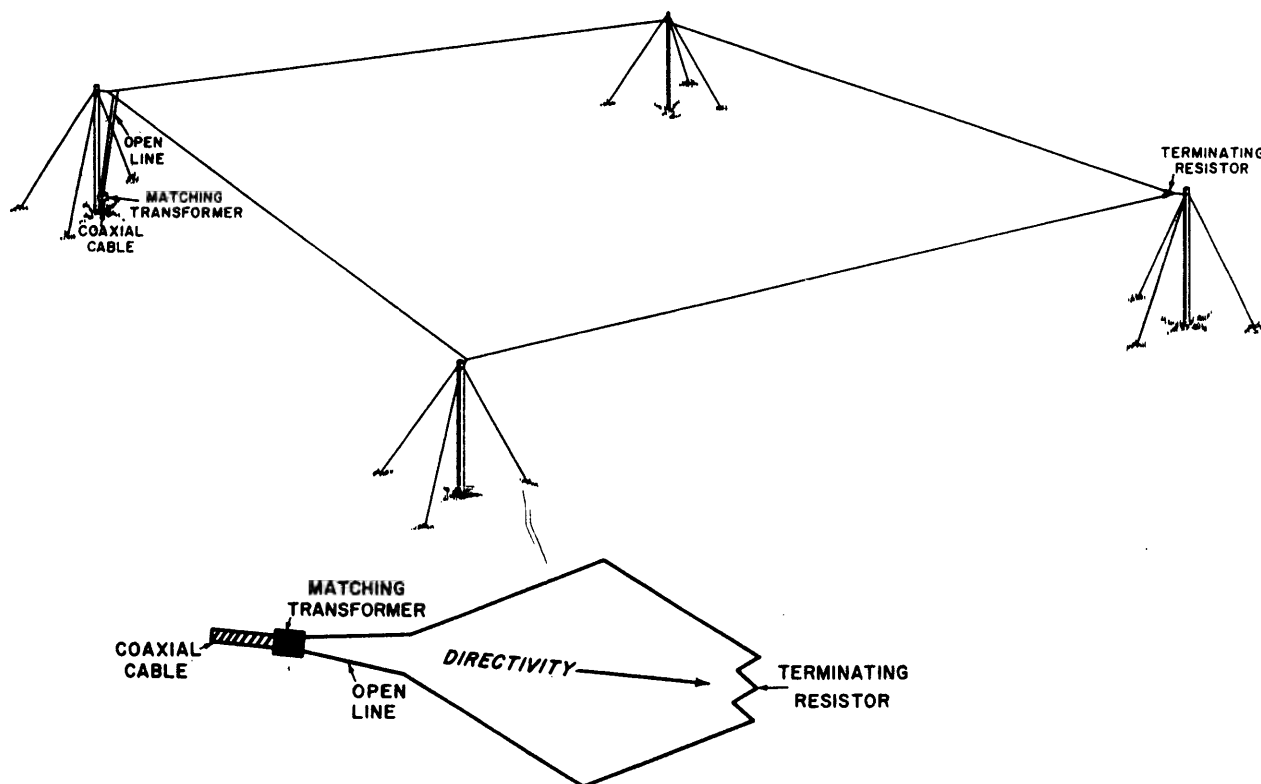
34.3

Figure 3-26.—Rhombic Antenna.

as shown schematically in figure 3-27, the inner rhombic might be designed for operation in the 10 to 28 MHz range; the outer for the 4 to 10 MHz range. The two rhombics are not connected together physically or electrically; however, both are connected to a common feed (rear) pole. Both antennas can be used in the selection of operating frequencies. The principal advantages of the "nested" configuration are reduced installation costs and more effective utilization of land.

End-Fire Antenna Array

The end-fire antenna array is so named because the principal radiation is off the ends of the array; that is, the radiation is maximum in the plane of the elements. This array may be contrasted with the broadside array in which maximum radiation is perpendicular to the plane of the elements.

A simple end-fire array employing two vertical half-wave antennas spaced $\frac{\lambda}{2}$ wavelength apart and fed 180° out of phase is shown in figure 3-28. Because the two antennas are $\frac{\lambda}{2}$ wavelengths apart and fed 180° out of phase, radiated energy will reinforce along line 1-2 in the plane of the antennas. Likewise, radiated energy is cancelled along line 3-4, broadside to the antennas.

If the spacing of the antennas is reduced to $\frac{\lambda}{4}$ wavelength, and the excitation of A lags that of B by 90°, a cardioid (heart-shaped) pattern is produced, as illustrated in figure 3-29.

Log-Periodic Antenna

An antenna arranged so that the electrical length and spacing between successive elements causes the input impedance and pattern to be repeated periodically with the logarithm of the
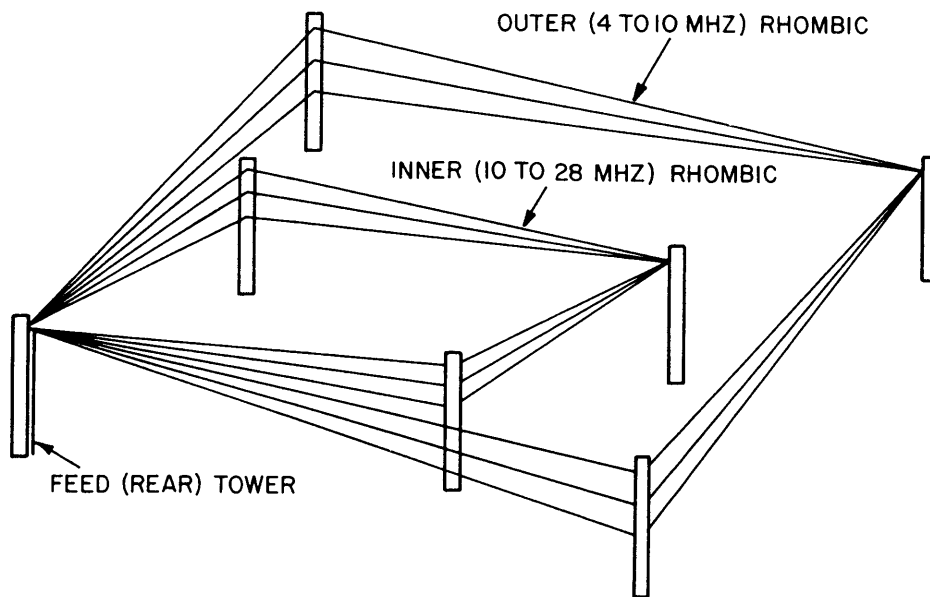
OUTER (4 TO 10 MHZ) RHOMBIC

INNER (10 TO 28 MHZ) RHOMBIC

FEED (REAR) TOWER

1.388

Figure 3-27.—Nested Rhombic Configuration.

93.28

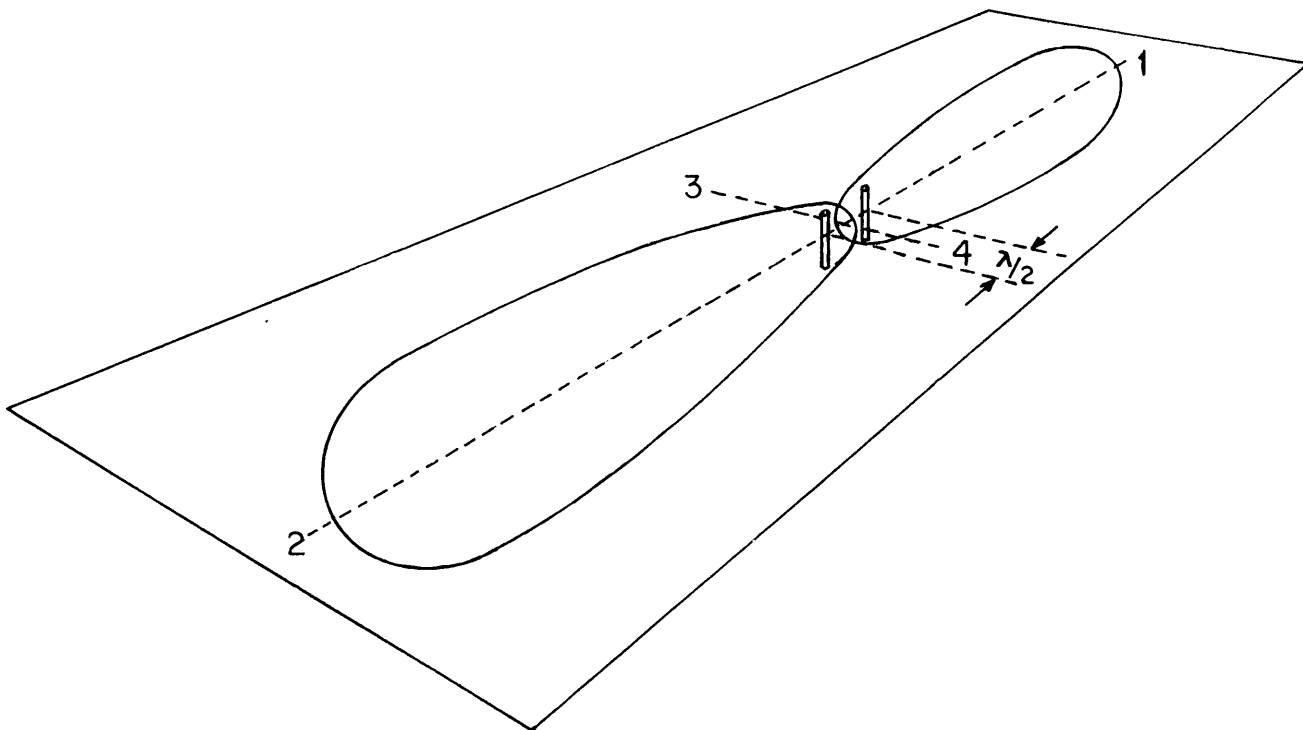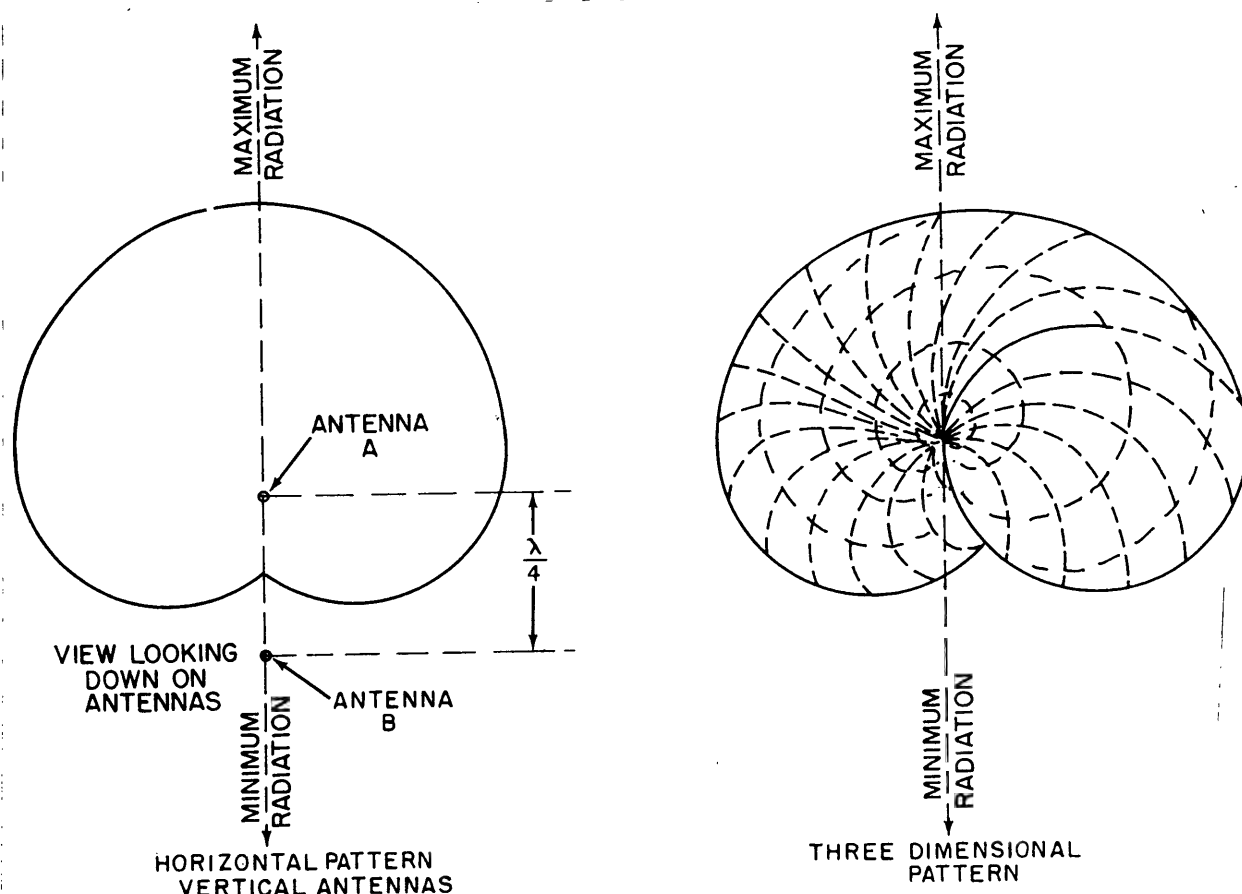**Figure 3-28.—End-Fire Array with Half-Wave Spacing.**

25.233

Figure 3-29.—End-Fire Array with Quarter-Wave Spacing.

driving frequency is called a log-periodic antenna (LPA). Both fixed-azimuth and rotatable LPA's are widely used in naval communications. Figure 3-30 illustrates two LPA's combined in a Vee formation to form a rotatable VLPA. Combining LPA's in this manner increases directivity and gain. Close inspection of the antenna in figure 3-30 will reveal that as the lengths of the elements increases, the spacing between successive elements also increases.

In an ideal log-periodic antenna, this repetition is scaled to vary with the logarithm of the frequency. For purposes of explaining the theory of operation of log-periodic antennas, the log-periodic dipole array in figure 3-31 will be used.

In this figure, assume that you have constructed a dipole antenna with dimensions equal to the longest pair of elements. Next to it you construct another dipole antenna resonant at some multiple of the original dipole resonant frequency. The elements are naturally shorter. Continue constructing dipole antennas which are resonant at increasing multiples of the basic frequency. If the dipoles are placed parallel to each other so that their tips are lined up as in the figure, the spacing between adjacent pairs will follow the same ratio as the lengths of the adjacent pairs.

If this analogy is modified so that the adjacent dipoles vary in size with the logarithm of the frequency, the same spacing relationship holds true, and the electrical properties of the antenna structure repeat periodically with the logarithm of the frequency. Since it is not physically possible to decrease the size of the
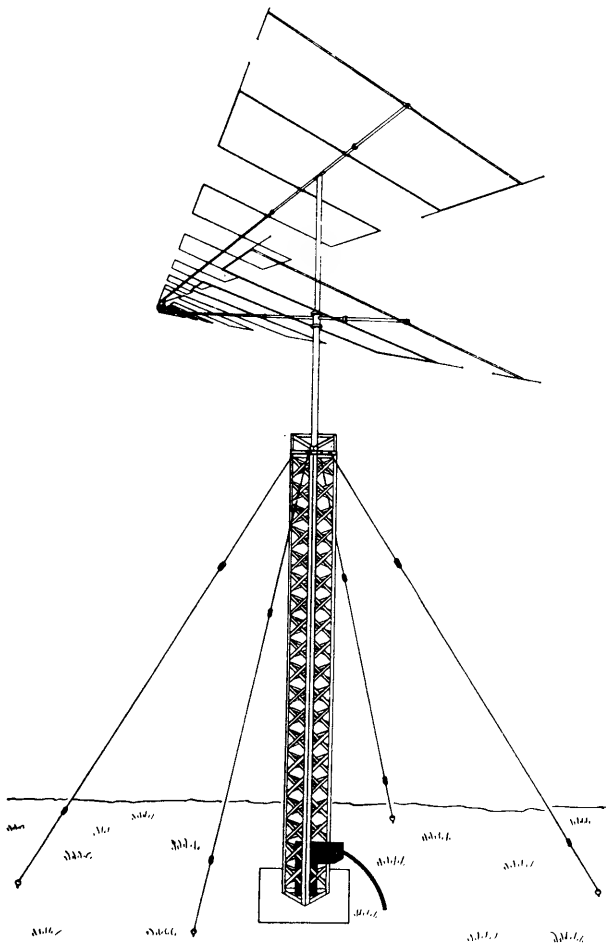
69

dipoles indefinitely, a high-frequency cutoff occurs when the shortest element is about one-quarter wavelength long. The low-frequency cutoff occurs when the longest element is also about one-quarter wave-length.

The result of lumping all the dipoles together in this special physical relationship is an antenna with relatively small impedance or gain variations over its operating frequency range. Thus, the effective electrical aperture of the antenna is essentially independent of frequency, since the wave, whether incoming or outgoing, travels along the structure until it strikes a dipole combination with which it resonates.

Fixed vertical LPA's are used at shore communication stations. Figure 3-32 is a simplified layout of a fixed VLPA. The three towers and the Vee wires are fed simultaneously by coaxial cable at a 75 ohm point above ground. The Vee wire radiators are held in place by nylon lines at the top and metal tiedown arms at the bottom. The tiedown arms and the towers are connected by wires to form a ground plane. The antenna radiates toward the support post end.

Circularly Disposed Antenna Array

The Circularly Disposed Antenna Array (CDAA) or Wullenweber antenna, as used for communications, is a multiple-function receiving antenna array that can produce simultaneously an omnidirectional pattern and several directional beams. The term array, as applied to
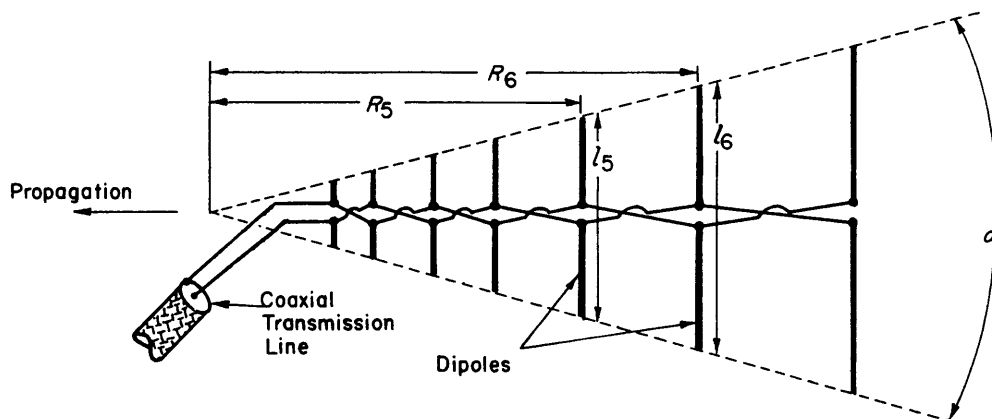

67.125

Figure 3-30.—Log Periodic Antenna.

25.283

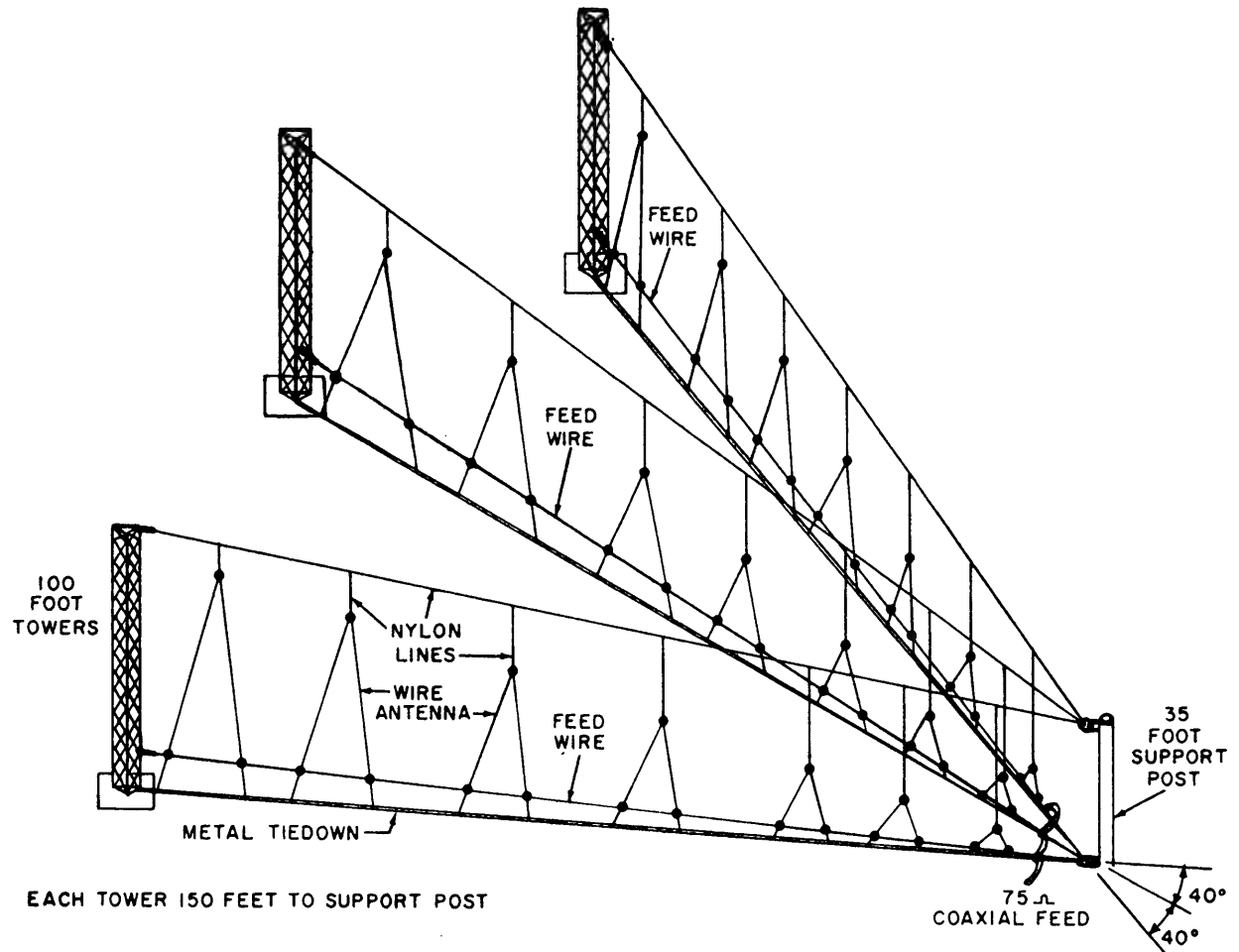Figure 3-31.—Log Periodic Dipole Array.

Figure 3-32.—Vertical Fixed Periodic Antenna 3-30 MHz.

27.126

antennas, is an arrangement of several individual antennas so spaced and phased that their individual contributions to the antenna pattern add in one or more preferred directions while cancelling in others. The individual antennas in the array are referred to as elements of the array. The array consists of numerous vertical antennas symmetrically located around a cylindrical screen as may be seen in figure 3-33. All of the antennas are connected to multicouplers with transmission lines precisely cut to equal electrical lengths so that the phase delay will be the same for all lines. The outputs of these multicouplers can be used in the following ways:

a. To select an individual antenna for a specific receiver.

b. To combine selected antennas to operate as an omnidirectional antenna.

c. To combine signals from several selected antennas through beam-forming (delay-line) networks to produce a high-gain directional beam pattern.

Several beam-forming networks are included so that a corresponding number of beams may be formed. These beams are aimed in appropriate directions to meet operational requirements.

71

25.117

Figure 3-33.—Circularly Disposed Antenna Array (CDAA).

Thus, several optional antenna patterns are available for use with any receiver; an omnidirectional pattern, a pattern composed of several beams or any individual antenna beam pattern. Figure 3-34 is a simplified block diagram for a hypothetical communications-type CDAA illustrating some of its capabilities.

Figure 3-33 is a CDAA consisting of two concentric bands designed to receive HF signals. The 40-element low-band array covers the 2 thru 8 MHz range and the 120-element high-band array covers the 8 thru 32 MHz range. Each array has its own screen while sharing a common ground mat. Figure 3-35 is a section of a CDAA showing the major elements of the array. The CDAA can be characterized as a high (12 to 14 dB) gain wideband, extremely versatile antenna, for HF receiving purposes. Compared to a rhombic antenna park with approximately the same capabilities, the CDAA requires much less land area. The radius of the high-band array is approximately 133.2 meters (437 feet) and the radius out to the edge of the radials if approximately 196.3 meters (644 feet). Compare this with figure 3-36, which represents a typical receiver station layout utilizing conventional antennas, and the difference in size becomes apparent. However, the CDAA's complex RF distribution and beamforming networks, plus the extensive site preparation necessary, may require much greater time, effort, and expense than other HF antenna systems. CDAAs are extensively utilized in HF direction finding applications.

RF TRANSMISSION LINES

Basically, an antenna serves to match the impedance of space to the output impedance of a transmitter or to couple the impedance of space to the input impedance of a receiver. Because the antenna is normally some distance from the equipment, a method of transferring
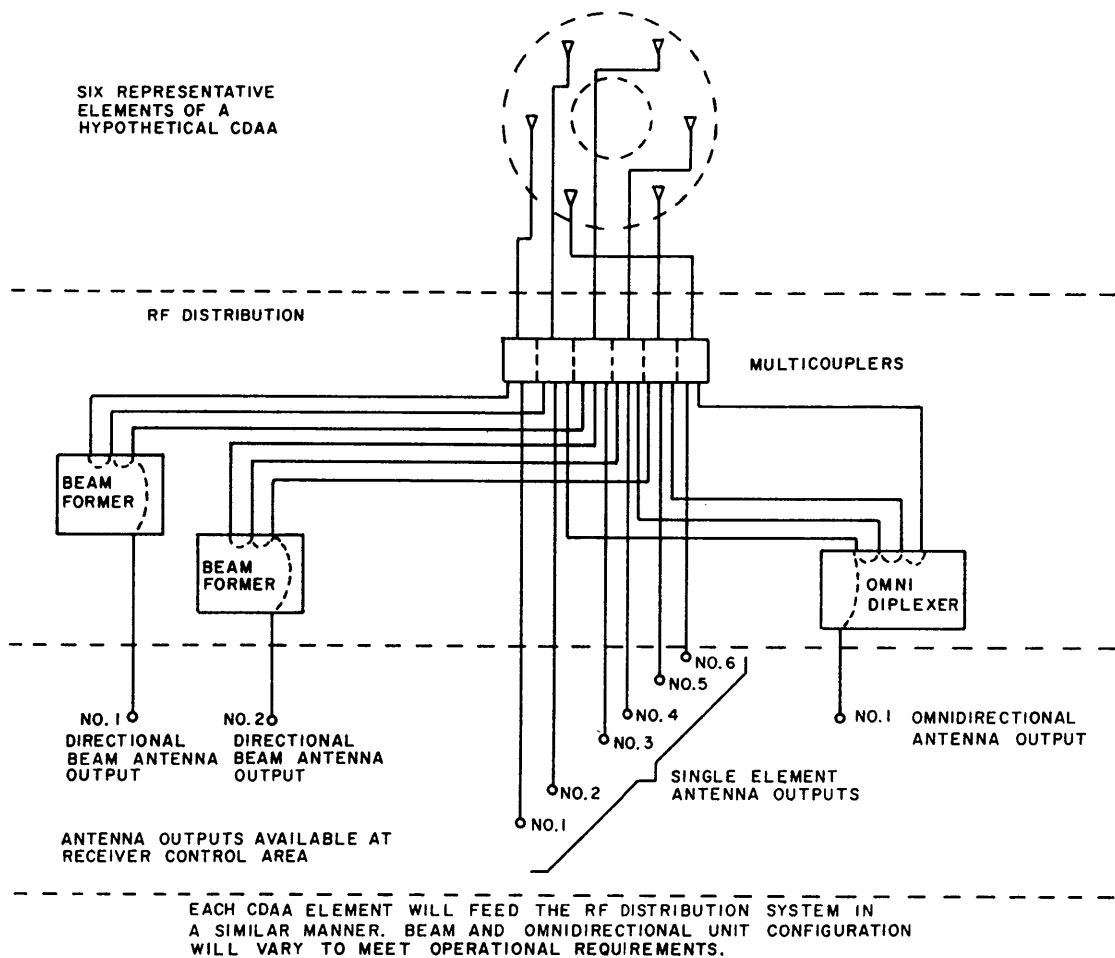
SIX REPRESENTATIVE
ELEMENTS OF A
HYPOTHETICAL CDAA

RF DISTRIBUTION

MULTICOUPLERS

BEAM FORMER

BEAM FORMER

OMNI DIPLEXER

NO. 6
NO. 5
NO. 4
NO. 3

NO. I
DIRECTIONAL
BEAM ANTENNA
OUTPUT

NO. 2
DIRECTIONAL
BEAM ANTENNA
OUTPUT

NO. I OMNIDIRECTIONAL
ANTENNA OUTPUT

SINGLE ELEMENT
ANTENNA OUTPUTS

NO. 2

NO. I

ANTENNA OUTPUTS AVAILABLE AT
RECEIVER CONTROL AREA

EACH CDAA ELEMENT WILL FEED THE RF DISTRIBUTION SYSTEM IN
A SIMILAR MANNER. BEAM AND OMNIDIRECTIONAL UNIT CONFIGURATION
WILL VARY TO MEET OPERATIONAL REQUIREMENTS.

1.389

Figure 3-34.—Typical CDAA RF Output Capabilities.

(or coupling) maximum power between the antenna and the equipment must be provided. One method of coupling is via a transmission line. If at all possible, the impedance of the transmission line and the input impedance of the load are made equal. However, this is not practical in most cases.

Impedance-matching devices are used to obtain the proper conditions for transferring maximum power, even with wide variations in the original impedances.

The input impedance of a receiver is usually about the same as the transmitter output impedance when conventional coaxial connectors are used. It is often possible to match the transmission line impedance to the input of a receiver or the output of a transmitter by means of a simple inductive coupling system. In other cases, a more complex system is required.

RF transmission lines are either flexible or rigid. Both types are used in naval installations, and type used is generally determined by the antenna and the individual application.

ANTENNA MULTICOUPLERS

Because of the large number of receivers included in each individual installation, it is
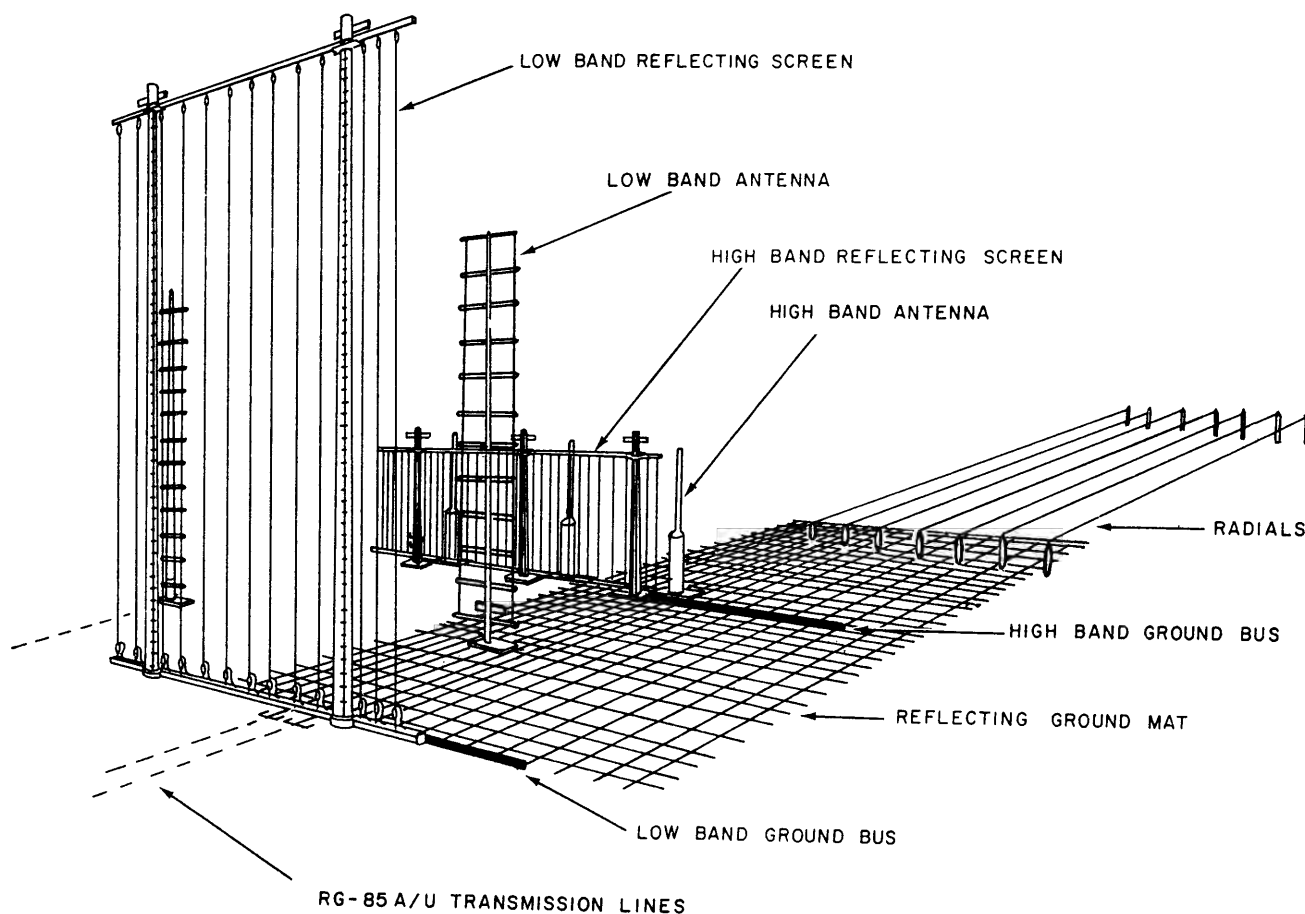
LOW BAND REFLECTING SCREEN

LOW BAND ANTENNA

HIGH BAND REFLECTING SCREEN

HIGH BAND ANTENNA

RADIALS

HIGH BAND GROUND BUS

REFLECTING GROUND MAT

LOW BAND GROUND BUS

RG-85 A/U TRANSMISSION LINES

1.390

Figure 3-35.—Major Components of a Typical CDAA.

impractical, if not impossible, to use separate antennas for the various equipments because of space limitations. It is possible to use one antenna over a wide range of frequencies, provided the antenna system is properly tuned and coupled to the equipment, so that the antenna appears as a non-reactive (pure resistance) load. It is also possible to use a coupling system that allows operation of several transmitters and/or receivers at the same time. It is not, however, normally possible to use an antenna for both transmitting and receiving simultaneously.

One satisfactory approach to the problem of insufficient numbers of antennas is provided by multicouplers. The multicouplers that are discussed in this chapter are only representative of those in current use at naval installations.

HF Multicoupler

ANTENNA COUPLER CU-872/U.—Antenna Coupler CU-872/U (figure 3-37) is one example of a typical HF electronic tube type multicoupler. The CU-872/U is designed to provide optimum coupling between a single antenna, and as many as eight receivers. Additional outputs from the same antenna are possible by connecting an output from a primary multicoupler to the input of a secondary multicoupler in a cascade (cascading is discussed below) arrangement as shown in
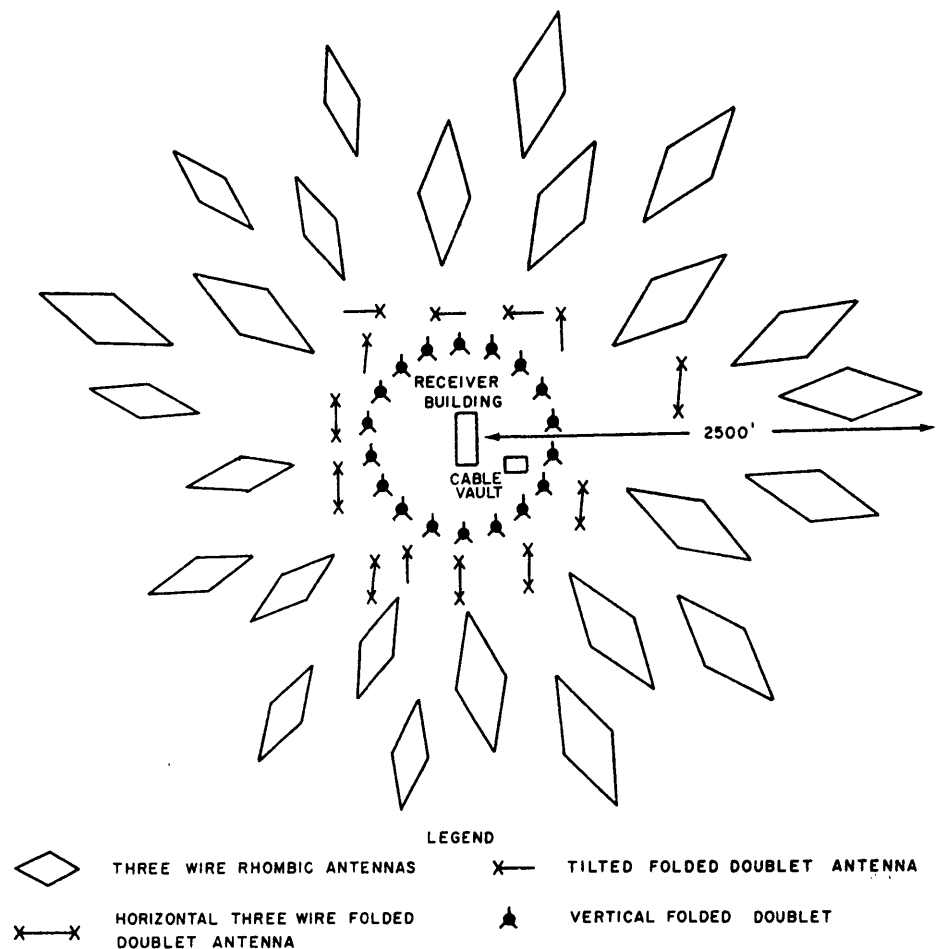
74

LEGEND

◇ THREE WIRE RHOMBIC ANTENNAS   ✗— TILTED FOLDED DOUBLET ANTENNA

✗—✗ HORIZONTAL THREE WIRE FOLDED DOUBLET ANTENNA   ⚓ VERTICAL FOLDED DOUBLET

1.391

Figure 3-36.—A Receiver Station Antenna Layout.

figure 3-38. A functional block diagram of the CU-872/U multicoupler is shown in figure 3-38. A 70-ohm input impedance is provided to match the impedance from the antenna. From the input connector, the signal is fed to low-pass/high-pass filters. These filters pass only the frequencies in the spectrum between 2.0 MHz and 32 MHz. Transformer T1 in the output circuit of the low-pass/high-pass filters, provides a transition between the low impedance unbalanced input circuits and a relatively high impedance balanced line. Each side of the balanced line drives one section of the push-pull distributed amplifier.

Tubes V1 through V5 and tubes V11 through V15, and their associated circuitry, comprise one-half of the push-pull distributed amplifier. Tubes V6 through V10 and tubes V16 through V20, and their associated circuitry, comprise the other half of the push-pull distributed amplifier. The distributed amplifier sections employ cascade stages (discussed below) along artificial transmission lines to obtain amplification over a wide bandwidth. The cascade amplifiers aid in reducing intermodulation by minimizing odd harmonic distortion. Additionally, employment of the distributed amplifier results in an improved signal-to-noise ratio. The distributed
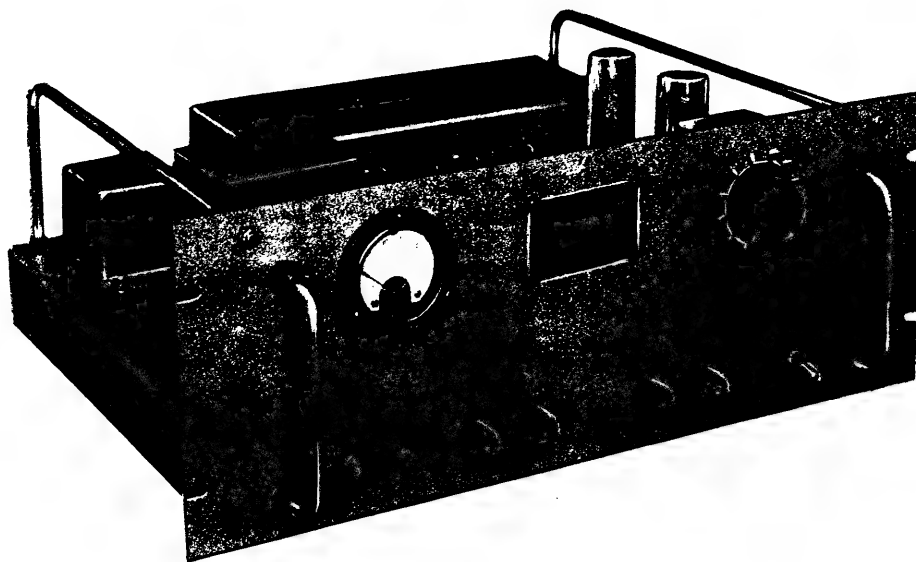
1.328

Figure 3-37.—Antenna Coupler CU-872/U.

amplifier sections drive transformer T2 in a push-pull manner, thereby reducing intermodulation by minimizing even harmonic distortion. The resulting signal, developed across the secondary winding of transformer T2, is applied to a cascaded hybrid network which distributes the amplified signal to eight isolated outputs.

ANTENNA COUPLER CU-1099/FRR.—The Antenna Coupler CU-1099/FRR is a broadband transistor RF amplifier which permits up to eight 70-ohm outputs to operate simultaneously off the same antenna. The unit operates over the frequency range of 2 to 32 MHz, with an input of 70 ohms. It uses 1/2 of the power (15 watts), one-half the space and is one third the weight of the CU-872. The units are usually mounted in pairs in a standard 48.26 centimeter (19 inch) bay using a mounting adapter. Figure 3-39 shows one bay of sixteen CU-1099s and two CU-872s.

A block diagram of the CU-1099/FRR is shown in figure 3-40. The signal input initially goes to a bandpass filter, A-201, which is made up of a high-pass and a low-pass filter, aligned to pass 2 to 32 MHz and attenuate all other frequencies. The bandpass filter output goes to a preamplifier, which consists of a single class A push-pull stage in which each half of the stage is made up of eight parallel transistor amplifiers. Low noise-high frequency transistor used in this configuration, makes possible wideband operation with a low-noise figure, low circuit impedance and relatively low gain. Push-pull design is used here, and elsewhere in the coupler, to minimize spurious effects from strong signals by cancelling even-order harmonics and intermodulation distortion products.

There are four output isolator circuits which provide up to 40 dB isolation between receiver circuits, regardless of the frequency to which a receiver is tuned. The output of Z-103 consists of two sets of signals 180 degrees out of phase with each other and with 176-ohms impedance between pairs. Two isolators are connected in series with each output of Z-103, and thus, each is matched to 88-ohms impedance. Z-3 in each isolator splits its input to match the 44-ohm input impedance of each of the two push-pull amplifiers in each isolator. The push-pull
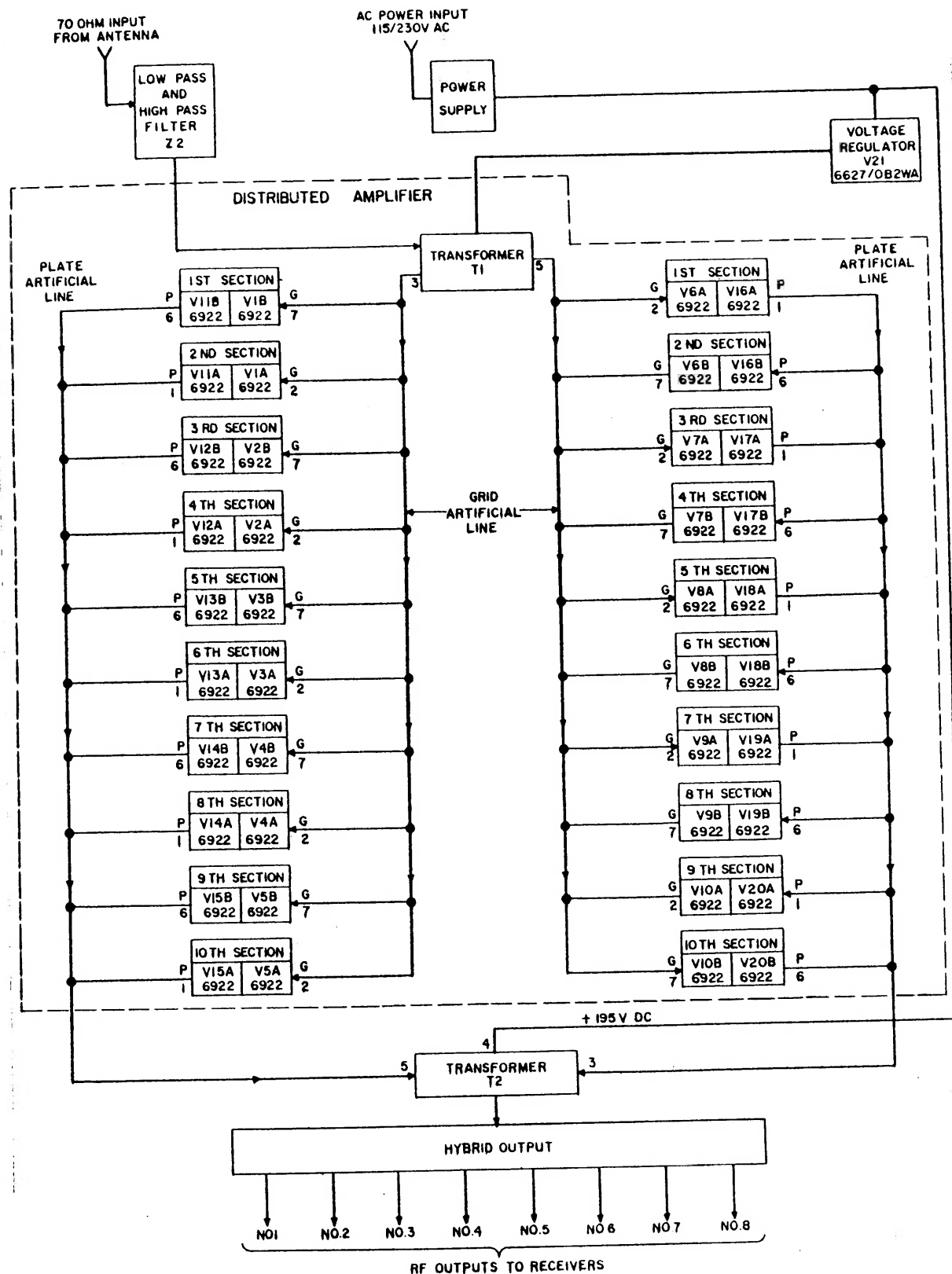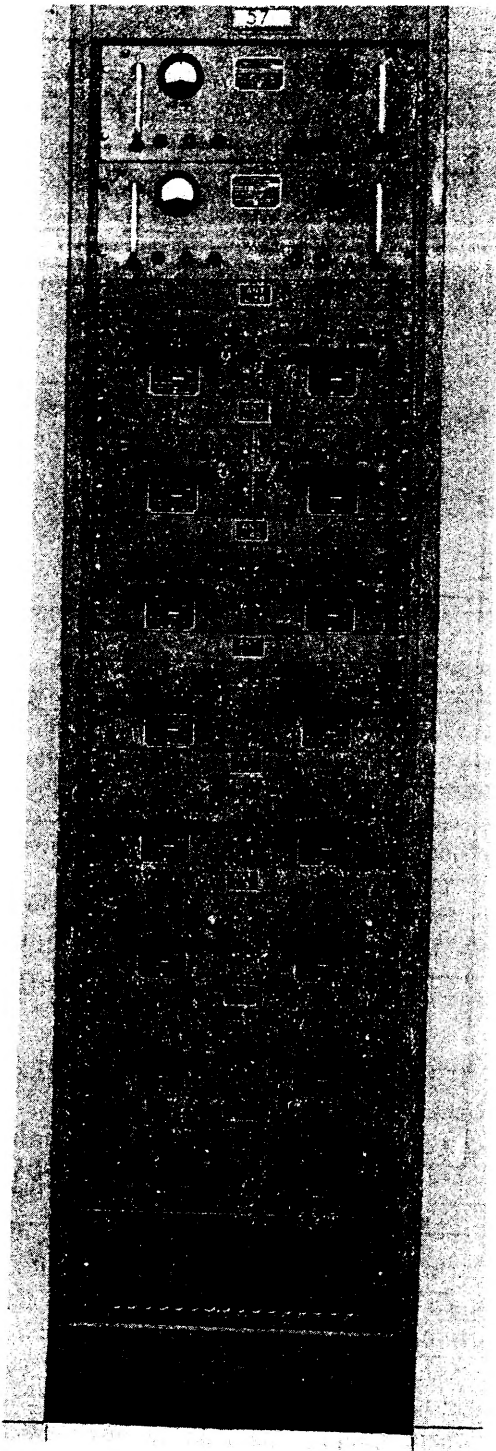
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Figure 3-38.—Antenna Coupler CU-872/U Functional Block Diagram.
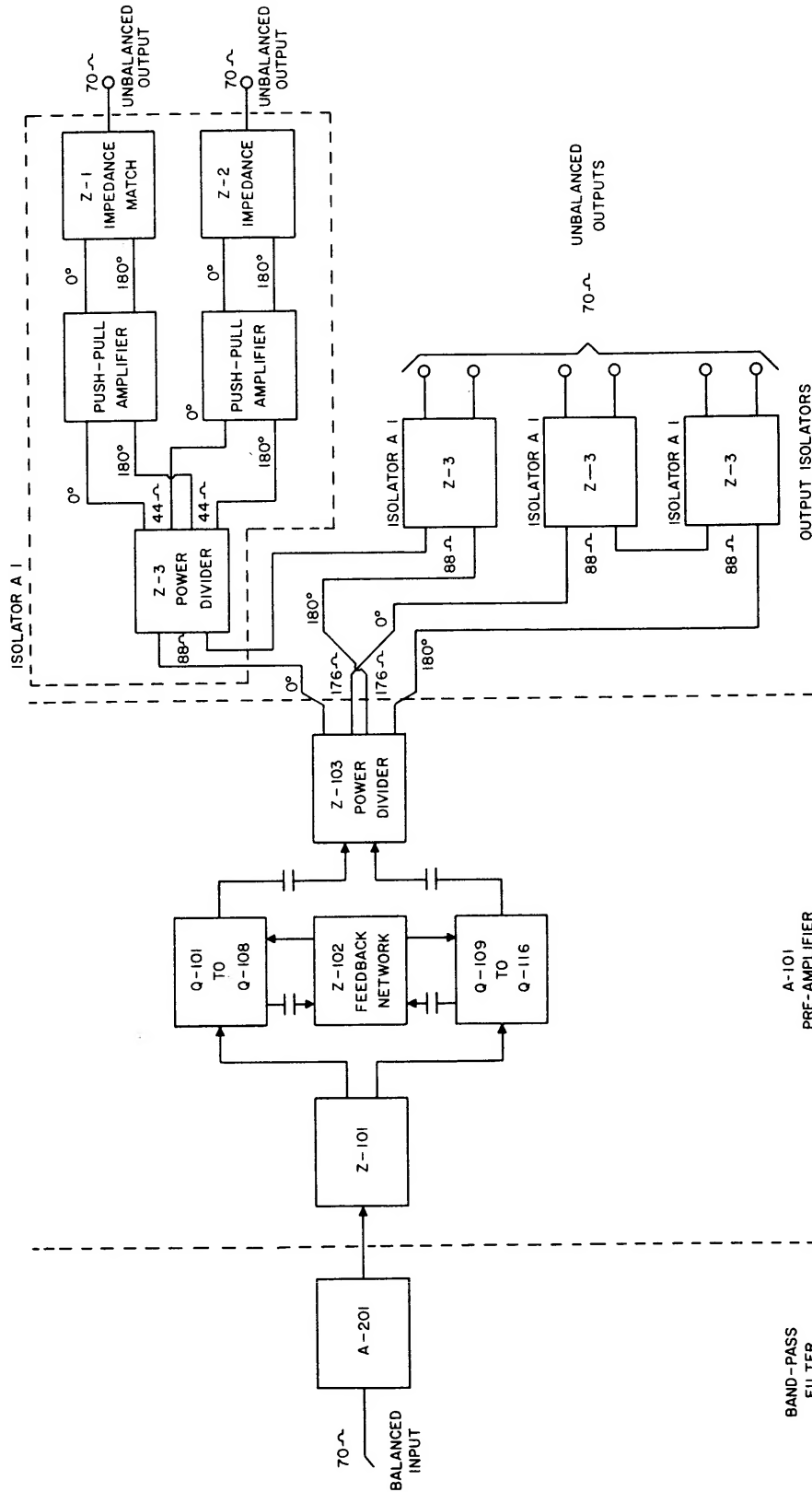
1. 329

amplifiers are made up of four transistors in a single stage, with two parallel transistors in each half of the stage. The balanced 630-ohm output is converted to an unbalanced 70 ohms by transformer action. The four plug-in isolator assemblies are mechanically identical, but each is electrically aligned for the position it occupies. The positions are marked A, B, C, and D with the B position (J-3 output), being the standard output used in factory alignment.

RF DISTRIBUTION

Normal Receiver Station Antenna RF Distribution

Antenna outputs are normally distributed as shown by figure 3-41. The patching equipment and RF multicouplers are normally collocated within the receiver building. All antenna transmission lines enter the receiver building through the cable vault where any necessary reduction in cable size or change of cable type takes place. RF distribution within the receiver building is usually accomplished with a smaller diameter cable than that used from the antenna to the building.

CASCADE ARRANGEMENT.—A large number of receivers can be fed from a single antenna by connecting multicouplers in cascade. A cascade arrangement, or connection, is one in which a normal ouput of one amplifier stage or multicoupler is used as the input to a second amplifier stage or multicoupler as shown in figure 3-38 and 3-41. An important consideration regarding the use of cascade connections is that as additional stages are added, there is a gradual decrease in the quality of the outputs. To obtain the best quality signal, it is most desirable to limit the number of cascaded connections. Generally, if more outputs are required, it is better to use additional secondary multicouplers on primary multicoupler outputs than cascade multicouplers in series on secondary multicoupler outputs.

1.392

Figure 3-39.—C U - 1 0 9 9 / F R R Antenna Couplers Bay-Mounted in Pairs.

1.393

Figure 3-40.—CU-1099/FRR Block Diagram.

79

NOTES:

1. NESTED RHOMBICS POINTED IN SAME DIRECTION AND USED FOR SPACE DIVERSITY

2. VEE LOG-PERIODICS POINTED IN SAME DIRECTION AND USED FOR SPACE DIVERSITY

3. EACH ANTENNA HAS ITS OWN TRANSMISSION LINE. TRANSMISSION LINES ARE GROUPED TO SIMPLIFY ROUTING THROUGH ANTENNA FIELD

LEGEND

◊ NESTED RHOMBIC ANTENNA

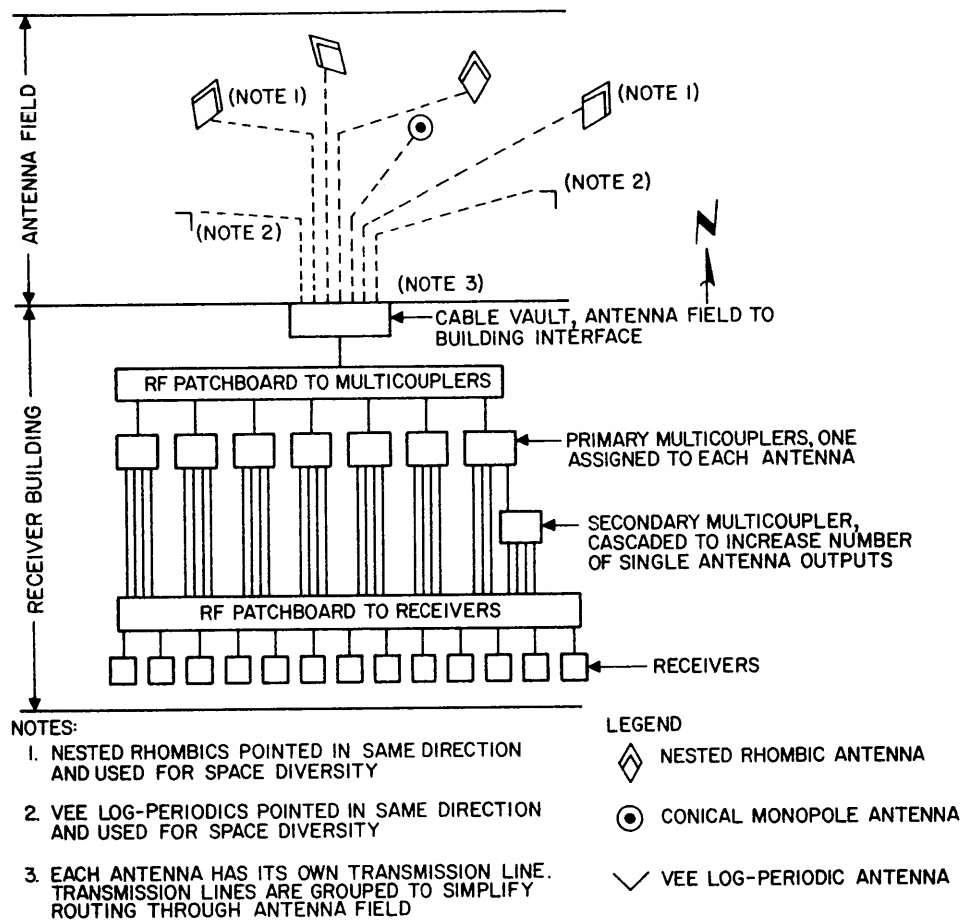⊙ CONICAL MONOPOLE ANTENNA

∨ VEE LOG-PERIODIC ANTENNA

1.394

Figure 3-41.—Normal Receiver Station Antenna RF Distribution.